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# Lectures in AEROSPACE MEDICINE

16-20 JANUARY 1961

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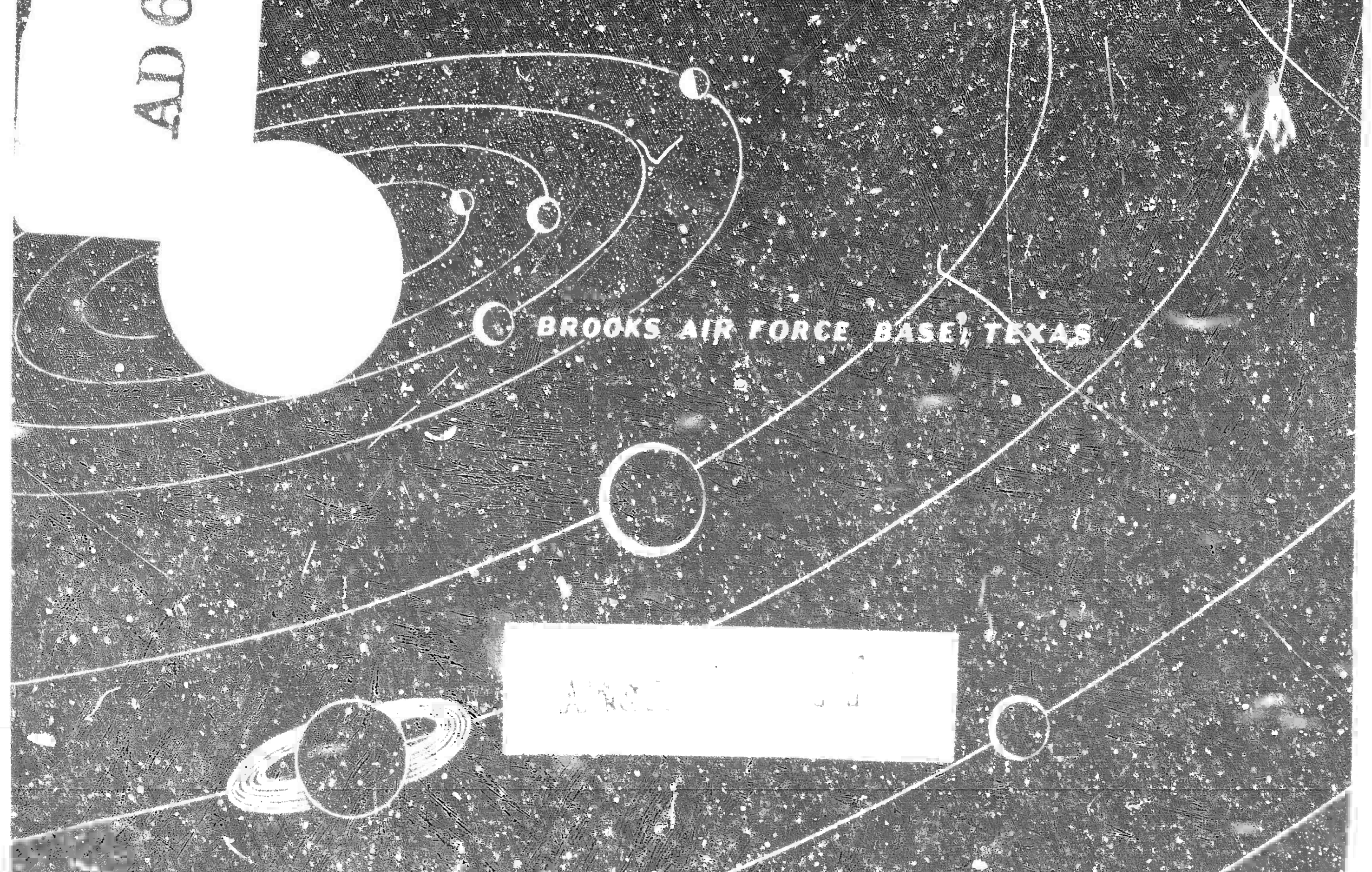
... AEROSPACE MEDICAL CENTER (ATC)



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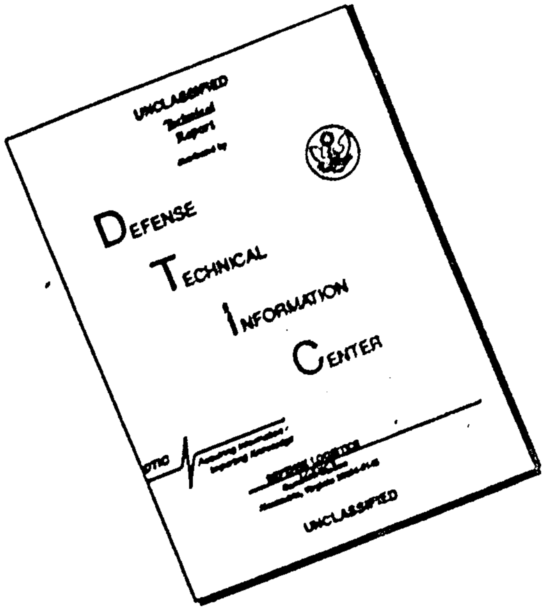


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# LECTURES IN AEROSPACE MEDICINE

16 thru 20 January 1961

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# LECTURES IN AEROSPACE MEDICINE

## INTRODUCTION

Presented by

COLONEL ROBERT H. BLOUNT, USAF, MC

Commandant

School of Aviation Medicine

# LECTURES IN AEROSPACE MEDICINE

## INTRODUCTION

by

COLONEL ROBERT H. BLOUNT, USAF, MC
COMMANDANT
SCHOOL OF AVIATION MEDICINE

I feel greatly honored to welcome you to this second series of "Lectures in Aerospace Medicine" at the School of Aviation Medicine. If we compare the titles of this year's lectures with those of last year, we recognize many of the same topics and perhaps the same speakers. I want to emphasize, however, that additional data will be forthcoming from this nationally and internationally known group of experts who have accepted our invitation to appear as guest lecturers during the coming week.

I would be remiss if I failed to tell you of some of the accomplishments made by our own staff during the past year, the details of which you will hear later by the researchers themselves. Customary and expected advances in fundamental research were punctuated frequently by spectacular successes achieved under space and space-equivalent conditions.

Heading this series of successes were two biological flights from Wallops Island in which the Mercury Capsule was powered by the "Little Joe" rocket. At the request of the National Aeronautics and Space Administration, these flights included trained, instrumented monkeys, for the purpose of studying effects of acceleration, weightlessness, noise and vibration on biological and behavioural functions. As everyone now knows, the animals tolerated the stresses without serious difficulty. Sam and Miss Sam will be very happy to personally greet each of you during your tour of the School's facilities this Wednesday afternoon.

Somewhat later, true space flight was achieved with three mice (Sally, Amy and Moe) aboard an Atlas Missile which reached a very high altitude and traveled several thousand miles down range. The life cell which housed these animals, and miniaturized devices which permitted the transmission of viability data, were designed and built at the Aerospace Medical Center. All passengers were recovered alive and healthy, and each of the two females has already produced a normal litter. Long term studies of these animals and their progeny will, of course, be made.

Two very unusual opportunities for the study of radiobiological hazards associated with the Van Allen Belt and other space radiation sources were realized recently in orbital flights aboard Discoverer vehicles. Discoverer XVII in November 1960 carried an integrated package containing physical and biological dosimeters through approximately fifty hours of orbital flight, thirteen of which provided exposure to a massive flux of very high energy protons resulting from a major solar flare. Discoverer XVIII in December 1960 carried a similar package containing some eighty physical and biological targets. Preliminary analyses of both sets of results suggest that the orbital environment of Discoverer is safe with respect to normal cosmic radiation, but more careful analyses will have to precede any final conclusions.

Another series of high altitude experiments worthy of special note was accomplished during the summer of 1960 when the School of Aviation Medicine joined with the Air Force Special Weapons Center to assess space radiation effects on plant and animal life. Four balloons, each carrying an integrated biological package, were successfully flown from a site in

Minnesota and recovered. Although some of the specimens exhibited radiation damage, most did not.

I must also mention that several studies involving partial simulation of the space environment were conducted in ground-based facilities and at conventional altitudes in the F-100F aircraft. Although less spectacular than true-space experiments, they have nevertheless contributed heavily toward the understanding and control of man in a space environment. The most relevant of these was conducted in a sealed space cabin simulator in which two Air Force officers successfully completed a "flight" of slightly over thirty days. This flight not only permitted an assessment of the chamber as an experimental facility, but it also furnished extensive data on the physiological and behavioural effects of unusual gaseous environments, special diets, prolonged confinement, and semi-isolation.

The problem of weightlessness, particularly difficult to study in a gravitational field, was approached through two radically different methods, parabolic profiles in the F-100F aircraft and prolonged periods of water immersions, with correlated studies of physiological and psychological variables. Successes in

this area have depended markedly upon the School's very substantial capability in bioelectronic instrumentation.

Why do I tell you of our achievements? May I quote Major General Otis O. Benson, Jr. in his opening remarks of last year? He said, "We dare to offer this series of Aerospace Medical Lectures because we feel that we have a modicum of both tradition and experience in these fields," unquote.

Ladies and Gentlemen, our experience has increased considerably this past year, our scientists are more confident, and the Aerospace Medical Center is now, and will become increasingly so, the very hub of bioastronautics research and development throughout the free world. That is why we will continue to offer this series of lectures.

In concluding, I feel that the following information pertaining to the composition of our distinguished audience for this lecture series might be of interest to you. We have:

| | |
|---|---|
| Distinguished representatives from Allied Nations | 28 |
| Representatives from MEND Program | 42 |
| Officers of the Air Force | 49 |
| Officers of the Army | 15 |
| Officers of the Navy | 5 |

| | |
|---|---|
| Air Force Reserve Officers . . . . . . . | 30 |
| Officers of the Air National Guard. . . . | 15 |
| Representatives of the National Aeronautics & Space Administration . | 3 |
| Representatives of the Federal Aviation Agency . . | 6 |
| Representatives of the Aerospace Medical Association . . . . . . . . . | 32 |
| Graduate Resident Students . . . . . . . | 15 |
| Program Participants (Speakers and Chairmen) . . . . . . . . . . . . . . . | 30 |
| Representatives from Universities, Research Foundations and Private Industry . . . . . . . . . . . . . . | 115 |
| TOTAL | 385 |

May each of you, in whatever capacity you now serve, be inspired anew to contribute to the advancement of man's knowledge in this international endeavor in the conquest of space. I am grateful to you all for the sacrifices made in order to attend our program this week, and sincerely hope that you may visit us again next year.

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# LECTURES IN AEROSPACE MEDICINE

## BIOPHYSICS OF THE SPACE ENVIRONMENT

Presented By

Hubertus Strughold, M.D., Ph.D.

Professor of Space Medicine-Advisor for Research

USAF Aerospace Medical Center (ATC)

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BIOPHYSICS OF THE SPACE ENVIRONMENT**

By

Hubertus Strughold, MD, PhD**

Ladies and Gentlemen: I consider it a great privilege to begin this International Aerospace Medical Lecture series with a discussion of the "Biophysics of the Space Environment."

From the viewpoint of biophysics for the purpose of manned space flight we must consider space under the following basic aspects:

1. Space as a "vacuum" environment with its various general physiological and sensory physiological consequences.

2. Space as an environment containing matter such as meteoric material, dust particles, molecules, and atoms.

3. Space as an environment of particle or corpuscular rays, including cosmic rays of both solar and galactic origin.

4. Space as a wave radiation environment with the sun as the dominating source, considered with regard to the three ecological important sections of the electromagnetic spectrum: heat radiation, visible radiation, and shortwave ionizing radiation.

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NOTE: This manuscript reflects the views of the author and should not be considered official Air Force policy.

5. Space as a magnetic field force environment which per se has no direct effect upon the astronaut but is indirectly very involved because of its influence upon the topographical distribution of energetic particles.

6. Space as an environment of gravitational forces, which determines the distribution and kinetic energy of meteoric material and, as a background factor, influence the velocities of space vehicles, their routes and time of exposure to some of the space factors.

Now the environment of space is not uniform throughout the solar system. It shows tremendous topographical variations and temporal fluctuations in most of the environmental conditions. This leads us to a kind of "geography" of space or, more to the point, to a Spatiography. A topographical space chart of this kind must, of course, include the question, where above the earth's surface and above that of the neighboring celestial bodies the various space factors begin. Especially, the inclusion of the earth's higher, partially space-equivalent, atmospheric strata is important because they may become the operational regions for new types of aerospace craft. It also conforms better with the title of this aerospace medical lecture series.

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Some of the aforementioned space factors such as meteoric material, high energy particles their concentration in magnetic fields and other ionizing radiations will be discussed in special lectures. In order to avoid duplication, I would like to confine myself to some biotechnologic aspects of the vacuum characteristics of space, to some conditions in space which are specifically related to our special senses such as communication, light and thermal radiations, and finally to the gravitational conditions, which are, in addition to propulsion, responsible for the topographical and time pattern of space flight trajectories.

a. <u>Biotechnologic aspect of space as a "vacuum" environment</u>. Space is usually referred to as "empty space" or a "vacuum." Containing only a few gas particles in 1 $cm^3$ it is--in the sense of physical definition--an extreme vacuum with a pressure in the order of $10^{-14}$mm Hg; for comparison, the best vacuum obtainable in the laboratory is in the order of $10^{-10}$mm Hg.

The chemical constituterts of this gaseous medium include hydrogen, oxygen, nitrogen, sodium, and others. Hydrogen is predominant. Most of these elements, at least in the inner portion of the solar space, are ionized by ultraviolet of solar radiation. Consequently, space contains ions and electrons. In addition, the sun continuously--and especially after flares--emits large amounts

of electrons. Furthermore, the solar corona which consists essentially of electrons may reach as far as the distance of the earth. The total number of electrons at the earth's orbital distance is about one hundred to several hundreds per 1 $cm^3$. Electrically charged gaseous material is called plasma. Thus, the environment of space is a very thin plasmatic medium, at least within the realm of the inner planets.

Now, from a physiologic point of view space is an extreme vacuum even though there are some topographical density variations in the gaseous and plasmatic medium. The only question--but a very important one--remaining is: how deep into the earth's atmosphere does this vacuum condition reach from a physiological standpoint or, as seen from the earth's surface, at what altitude do the physiological vacuum effects become significant? As has been shown by H. G. Armstrong, 1935 (1), at an airpressure of 47 mm Hg the body fluids at a temperature of 37°C start to boil just the same as if there were no pressure at all, as in space. Biobarometrically, at this pressure level, the vacuum begins for the human body, and since 47 mm Hg corresponds to a height of about 20 km (12 mi), at this altitude the atmosphere becomes space--equivalent in this respect. On Mars this condition is found at an altitude of 3 1/2 km (2 1/4 mi).

Compared with the critical effects of hypoxia and dysbarism, ebullism, as body fluid boiling is called (J. Ward) (2), represents a hypercritical condition for the human body and requires at its threshold the same antivacuum protection (full pressure suit) as in the hard vacuum of space or on the moon, which has such a rarified atmosphere that its surface pressure is as low as that found on earth at an altitude of 100 km (62 mi). Biotechnologically, a vehicle flying above the 20 km level is an aerospace craft. But from the standpoint of flight dynamics it still follows the laws of aerodynamics as an airplane. The pertinent characteristics, namely aerodynamic lift and navigation by control surfaces, terminate around 80 to 100 km (50 to 60 mi), which is called the von Karman line. Extended regions below this line have remained, so far, virgin areas in aviation, but the development of new high performance aerospace vehicles such as the B-70 may change this situation, which will put these altitudes into the focus of aerospace medical attention.

The von Karman line is the dividing line between aerodynamics and ballistics. From here on navigation by control surfaces has to be replaced by reaction control. But there is still air resistance producing drag. This aerodynamic effect comes to an end at the "mechanical border" of the atmosphere: around 200 km (120 mi) (H. Haber) (3)

This is the dividing line between ballistics and celestial mechanics, or astrodynamics. Above this line we encounter permanent weightlessness. Dipping below this line produces the sensation of weight which will gradually occur in a returning winged space vehicle, a design which from a medical point of view can take advantage of the aerodynamic navigation possibilities, at least below the von Karman line. Incidentally, last September the International Aeronautical Federation in Geneva tentatively agreed to call a vehicle flying beyond 100 km (62 mi), which is the extreme value for the von Karman line, a space craft.

But satellite flight, the first phase of true space flight, is possible for some duration only above the mechanical border of the atmosphere (200 km). If we ignore air resistance or drag effect encountered by a fast flying vehicle, most of the natural physical environmental space conditions are found at somewhat lower altitudes. Nevertheless, we shall use as an observation altitude for our further discussion of the space environment that of 500 km (300 mi) as a kind of standard orbit which is located in a true space environment and yet not too far away from the earth's effective atmosphere and just below Van Allen's radiation belt.

b. Space as a communication environment. In the foregoing discussion we began with some mechanical effects of the atmosphere and their absence in space. I would like to add another mechanical phenomenon; namely, propagation of sound which can be perceived by the human ear in the range from about 20 to 20,000 cycles per sec. In an environment with only 10 to 100 gas molecules in 1 $cm^3$ propagation of these mechanical vibrations is out of the question. Space therefore is deadly silent. Actually, this space characteristic appears gradually within the higher and upper atmosphere.

Robert Boyle (4) in the 17th century noticed that the sound of a little bell suspended by a silk thread inside an airtight glass globe connected to a vacuum pump, which he called "pneumatical engine," weakened when the air pressure therein was reduced.

And E. Schroedinger (5) in 1917 made calculations about the relation of sound propagation to the free pathway of the air molecules. As soon as the free path of the air molecules is in the order of the wave length of sound, propagation of sound ceases. The wave length of sound perceptable by the human ear is in the order of 1 cm to 15 meters. The free path of the air molecules approaches the length of sound waves in the higher stratosphere.

The result is that first waves of shorter length or the higher tones are damped out and finally as altitude increases the lower tones also disappear. The region where this occurs lies between 80 to 160 km (50 to 100 mi). The temperature of the atmosphere causes some variations. Nevertheless, with regard to transmissibility of the circumterrestrial environment for sound, we can differentiate three regions: the acoustic zone from sea level to 80 km (50 mi), the hypacoustic zone from 80 km to 160 km (50 to 100 mi), and above this transitional zone the anacoustic void of space. It is here where silence of space begins. Sound barrier, Mach number, supersonic and hypersonic speeds now become meaningless; the latter replaced by the astronautical velocities.

From the outside the astronaut will hear nothing except the tiny tinny impact sounds of micrometeorites contrasting ominously against the deadly zero decibel environment of space. This, of course, does not mean that he is faced with a communicative accoustical isolation. Fortunately there is a radio window in the ionosphere which provides a communication channel with the ground stations. Basically, then, radio waves are the method of communication in space and also between astronauts walking on the moon, and preferably on Mars. This is, of course, different within the space cabin itself or on a moonbase which

contains an artificial atmosphere dense enough for sound propagation.

Another even more important sensory physiological function in space flight is vision, because in the weightless state the eye is the only sense organ that can provide information about orientation in space. This leads us to the discussion of--

c. Space as a photic environment. Actually the light conditions in space are of medico-biological interest in two respects:

with regard to vision, and

with regard to photosynthesis as a method for biological recycling of the respiratory and metabolic end products.

I shall confine myself to the human physiological aspect; namely, vision, since photosynthetic recycling will be discussed in a special lecture.

The retina of the human eye is sensitive to the range from 3800 to 7000 Å of the electromagnetic radiation spectrum. This is the physiologic optical window, through which we perceive the panorama of the world around us and of the Universe.

The light conditions in any environment are determined by the kind and distance of the light sources and the optical properties of the environment, i.e., transparency, its light refracting,

reflecting, scattering, and absorbing power. Illuminance, i.e., luminous flux incident on unit area expressed in lux or meter candle (formerly foot candle) and luminance of photometric brightness or luminous intensity of any surface expressed in nit (formerly in millilambert), are the two photometric terms and units of measure internationally used for a quantitative analysis of a photic environment. (See Annex)

We understand more clearly the exotic light conditions in space by comparing them with those in our familiar environment: the atmosphere. The atmosphere in its lower and higher regions contains quintillions to quadrillions gas molecules in 1 $cm^3$, and numerous aerosol particles. Space contains merely some 10 atoms and some hundred electrons in the same volume unit. This accounts for the photic differences between these environments. The strong atmospheric light-scattering, especially in the short wave portion of the visual spectrum, produces the blue sky light and reflection of light by ice crystals in the higher atmosphere, forms an aureole surrounding the sun and blurring its rim. Behind this veil of indirect sunlight the stars remain invisible and the moon is barely

discernible. On a cloudless noon at middle altitudes the luminance of the blue sky, about 25$^{\circ}$ from zenith is about 1600 nit (H. Haber), (3). And solar illuminance at sea level can reach intensities as high as 108,000 lux (H. Haber) (3); (E. O. Hulbert) (6).

In contrast, in the almost perfect vacuum of space there is no indirect sunlight by Raleigh scattering. The sky, therefore, is dark despite a bright shining sun. There is some faint background luminosity, the zodical light, which is also visible on earth. This is indirect sunlight reflected by dust and micrometeorites and may extend as far as the region of Jupiter. Nevertheless, the darkness of the sky in space is greater than the night sky on a moonless night on earth. It is the night air glow, a faint diffuse light emitted by atomic oxygen, nitrogen and sodium in the upper atmosphere brought into excited states by solar ultraviolet radiation, that gives the night sky on earth a slight bluish luminosity. Its luminance is in the order of $10^{-4}$ nit and that of the sky in space $10^{-5}$ nit, i.e., by a factor of 10 lower. The darkening of the sky begins even within the stratosphere as has been observed by Jean Pickard (7); A. W. Stevens and O. A. Anderson (8)

D. C. Simons (9), and M. D. Ross; and M. L. Lewis (10). At 30 km (18 mi) the luminance of the sky decreases to 30 nit and at 160 km (100 mi) the final value $10^{-5}$ nit is reached. This is the transitional zone from atmospheric optics to space optics.

Against the low field brightness of the sky in space the stars are visible at all times and they do not twinkle because no atmospheric turbulence interferes. Also because of the absence of a light-reflecting and light -scattering medium the sun now shines without an aureole as a luminous disk on a black backgroudd. The sun's <u>corona</u> which consists essentially of electrons and extends as far as the orbit of the earth, scatters some of the light emitted from the photosphere, amounting totally to one-half of the brightness of the full moon (M. Waldmeier) (11). But against the brilliance of the solar disk this will not be perceptible by the human eye.

Also, it might be interesting to learn whether or not astronauts will be able to perceive the so-called <u>Gegenschein</u>, or <u>counterglow</u>-- a faint luminosity far above the earth's atmosphere opposite the sun, the cause of which is still a matter of dispute. Some astronomers think it is solar light reflected from a concentration fo dust, others theorize that it is an airglow type of light produced in a miniature

cometray tail of atmospheric material which the earth might possess.

Solar illuminance at the top of our atmosphere amounts to roughly 140,000 lux (H. Haber, 3; F. S. Johnson, 12; R. B. Toolin and V. G. Stukatis, 13). This extra-atmospheric value is occasionally called the solar illuminance constant. At sea level, solar illuminance is maximally 108,000 lux, as already mentioned. Such are the basic differences between the atmospheric and extra-atmospheric photic environment in nearby space during the day: a bright sun shining out of a blue sky of indirect sunlight and a brilliant solar disk sharply contrasting against a permanent black surrounding.

The more or less evenly distributed, diffused illumination on earth--a very important general function of planetary atmospheres--is missing in space. The low field brightness or blackness of the sky in space combined with an intensive illumination from the sun, represents physiologically a strange optical situation approximated on earth only under artificial conditions; for example, in theatrical stage lighting. Everything that is exposed to sunlight--outside and inside the cabin--appears extremely bright; everything in the shadow is dark. Light and shadow dominate the scenery. This photoscotic condition poses problems in the field of contrast

vision and retinal adaption, and requires special attention in human engineering of the space cabin windows (P. Cibis, 14; H. W. Rose, 15).

Now, let's examine the light conditions in deep space including the whole solar system from Mercury to Pluto, (O. Ritter and H. Strughold, 16). The darkness of the sky does not change significantly except that it may become a shade darker in the extra-jovian space because of the disappearance of the zodiacal background light. Interesting to us is solar illuminance because it varies according to the inverse square to the distance law, Table I. Accordingly, the value of 140,000 lux found at the terrestrial orbital distance increases in the region of Venus to 270,000 lux and at Mercury's distance to 940,000 lux; it decreases at the distance of Mars to 60,000 lux; at Jupiter's distance to 5,200 lux; and at the mean orbital distance of Pluto to 90 lux. The extremes on both sides of this scale of solar illuminance represent--from a human physiological point of view--a hyperphotic and hypophotic zone with a more or less tolerable zone between the two, extending some 100 million km (60 million mi) in the sunward direction, and perhaps several 100 million km in the opposite direction, as seen from the earth's orbital distance. This euphotic or biophotic belt

together with the euthermal belt (see later) is an important component in the concept of a general life-favoring zone, or ecosphere, in the solar system (H. Strughold) (17).

At this point it might be interesting to consider the apparent size of the sun as seen at the distances of the various planets.

To an observer on Mercury, the diameter of the solar disk would appear more than twice as large as seen from the earth. As seen from Mars, the sun would have a considerably smaller apparent dimension--about two-thirds of the size familiar to us. At the distance of Jupiter, the sun's diameter is one-fifth as large; and at the distance of pluto, the sun would appear only about three times larger than the evening star (Venus) appears to us under the most favorable conditions.

And yet, the illuminance from the sun at the mean distance of Pluto is still 90 lux; this is considerably higher than the threshold for color vision. Below 10 lux, color discrimination becomes difficult. Solar illuminance decreases to this value in the region about three times the distance of Pluto, or about 18 billion km (or more than 10 billion mi) from the sun. Here, then, begins the colorless world of interstellar space, as far as it is related to the sun's illuminating

power. And the sun, itself, as seen with the eyes of an interstellar space traveler, gradually joins the conventional astronomical scale of stellar magnitudes.

Looking into the sun is hazardous, because this can cause a thermal coagulation of the retinal tissue or a retinal burn of the kind observed after atomic flashes or as often described in the ophthalmological literature under the name eclipse blindness, (scotoma heliecliptioum) which can be acquired if a solar eclipse is observed with an insufficiently smoked glass. In milder cases the injury may be a retinitis solaris. Precaution in this respect and protection of the eye by automatically functioning light and heat absorbing glasses are indicated (H. Strughold, O. L. Ritter) (18). The danger of a retinal burn is acute as long as the sun appears as a disk with an angular diameter larger than about 2 or 3 minutes of arc (O. L. Ritter) (19). This is the case as far as the distance of Saturn.

Now let us return to the photic scenery in the region of space which is of immediate interest to us: the arena of manned satellite flight, represented by our standard observation satellite at 500 km altitude. From this altitude a territory of nearly 5000 km (3000 mi) in diameter is within reach of the orbiting astronaut's eye. He will

have, of course, the impression that he is standing still in space and that the earth is rotating below him. Of special interest will be the earth as a source of light. The visible cap, if sunlit, may have a brightness ranging from 1000 to 30,000 nit, dependent upon the features of the landscape and cloud conditions. From a distance of about 6 earth radii, at which 90% of half of the planet can be overlooked, the mean albedo of the earth of 0.36 can become fully effective. At our assumed standard satellite height the illuminance of the solar light reflected from the earth can reach 20,000 lux (H. G. Merril) (20). This might easily cause a dazzling glare (as described for intra-atmospheric altitudes by T. C. McDonald (21), especially when the orbiting astronaut emerges out of the earth's shadow.

Not everywhere is there sunshine and earthshine in nearby space. There are the umbrae and penumbrae of the earth and of the other not self-luminous celestial bodies. (Table II). The umbra or full shadow of the earth extends in the form of a cone to 1,385,000 km; that of the moon to 375,000 km, and the giant shadow cone of Jupiter is 90 million km in length. These shadow cones are not visible to the astronaut, because of the absence of light-scattering gaseous matter. He will become aware of them only when he is moving through them,

in which case the sun is blocked out of the black sky. This is satellite night. The satellite night is always shorter than the satellite day. At our standard orbit it lasts only 33 minutes as compared with 61 minutes of the satellite day. Moving through the penumbrae represents dusk and dawn for the satellite occupants, lasting only several minutes at our orbital altitude. But there are, of course, many variations in the duration of the phases of the satellite day-night cycle, dependent upon the inclination of the orbit. This day-night cycle situation requires artificial day-night cycling of the astronaut's phases of sleep, rest, and activity, which will greatly be influenced by the state of weightlessness.

Now, the satellite night is not only a night from a photic point of view, it is also always a "cold" winter night because solar thermal irradiation is blocked out also.

d. The thermal environment of space. Knowledge of the thermal condition is important with regard to temperature control of the space cabin. But the temperature and heat problem in space is often misunderstood, because we usually think in terms of the heat climate on earth. Heat transfer in our atmosphere takes place by conduction, convection, and radiation.

In the extreme vacuum of space, heat transfer occurs exclusively by

radiation. Heat transfer by conduction from the few gaseous particles, even if they have a very high kinetic energy or temperature, is practically zero. Heat transfer by convection also does not occur in space except in cases when "hot" plasmatic material is blown into the region of the earth, but its density is too low to have any significant thermal effect upon a space vehicle. So, heat transfer by radiation remains practically the only type in space we have to reckon with.

At the top of the earth's atmosphere the intensity of heat irradiation (essentially infrared and visible light) is about 2 cal $cm^{-2}min^{-1}$, called the solar constant. On the earth's surface at noon, under favorable weather conditions thermal irradiance is never higher than two-thirds of this value, because of reflection of radiation back into space, and heat absorption by atmospheric water vapor and carbon dioxide. Using the terrestrial solar constant as a base line, thermal irradiance at the orbital distance of Venus nearly doubles, and in the region of Mercury it is more than six times as high, namely 13 cal $cm^{-2}min^{-1}$; at the distance of Mars it decreases to less than one-half; at Jupiter's distance to one-twenty-seventh, i.e., 0.7 cal $cm^{-2}min^{-1}$, and in the remote region of Pluto it drops to one sixteen-hundredths of

the terrestrial solar constant; namely a little over 0.001 cal $cm^{-2}min^{-1}$ Table I, (O. L. Ritter and Strughold) (16). Such is the thermal radiation climate in the solar space: extremes in its inner and outer portions and a somewhat temperate region on both sides of the orbit of the life-sustaining earth.

These extreme variations in solar thermal irradiance require modifications in cabin temperature control measures for interplanetary space operations or may even set limits to them. In the hyperthermal intra-venusian and certainly in the intramercurian space, astronauts would run into a kind of solar heat barrier as symbolized by the legendary flight of Icarus. A penetration into the hypothermal regions beyond Mars and Jupiter would make the sun's rays too weak for utilization in cabin temperature control, and would then require a sun independent, nuclear heating system. Both extreme situations are illustrated by an asteroid which comes very close to the sun and therefore has been called Icarus by its discoverer W. Baade, Mt. Palomar, 1949. But its very eccentric orbit, which has a period of revolution of 409 days, carries it also very far away from the sun. It has been estimated that the surface temperature of Icarus at its perihelion some 30 million km from

the sun or halfway between Mercury and the sun rises to some $500^{\circ}C$ and at the aphelion between Mars and Jupiter it should drop somewhat below the freezing point of water. This natural celestial body shows us what we can expect for an artificial celestial body in the hyperthermal and hypothermal regions of the solar space.

But presently and in the near future, we are more concerned with the situation encountered in the more or less temperate regions around the earth and up to Venus and Mars which we might call the euthermal belt in the solar system. An earth satellite orbiting below the Van Allen belt is exposed to 2 cal $cm^{-2}min^{-1}$. The temperatures measured within the shell of the Explorer and Vanguard satellites were well within the physiologically tolerable range, around $25^{\circ}C$. But here the shadow cones of the earth have to be included in our consideration. The slight variations in solar thermal irradiance on a trip to the 340,000 km distant moon are practically within the range of error of the terrestrial solar constant. An expedition to Venus has to reckon with a peak exposure of 4 cal $cm^{-2}min^{-1}$, and in the neighborhood of Mars a space ship will encounter a low of 0.9 cal $cm^{-2}min^{-1}$. This is a

difference of more than 3 cal $cm^{-2}min^{-1}$, which means that even within our euthermal zone it makes a great difference with regard to cabin temperature control whether the space ship is Venus bound or Mars-bound. The bioengineering problem in modifying the heat absorbing and reflecting surfaces, however, should not be too difficult to achieve a suitable equilibrium temperature (K. Buettner) (22). But it is also obvious that on very long-lasting space journeys (many months) the optical and thermal properties of the surface of space vehicles will deteriorate due to erosion by micrometeoritic material.

e. The gravitational environment of space. The picture of the biophysics of space is not complete if we do not include the gravitational situation in space, because the gravitational field forces determine to a great extent the routes and velocities of space vehicles, and consequently the duration of their exposure to the various environmental space factors. In astronautics we are particularly interested in the sphere of predominant influence of the gravitational field forces of a celestial body. We can call this volume unit in space, briefly, gravisphere (H. Strughold and O. L. Ritter) (23). We can actually differentiate between an

inner and an outer gravisphere. The inner gravisphere represents the region within which the gravitational attraction of a planet is able to hold a satellite in orbit. It is the potential satellite sphere. The outer gravisphere includes the distance beyond the potential satellite sphere within which the gravitational forces of a celestial body are still strong enough to cause considerable perturbations of the trajectory of a space vehicle. For us, of most importance is the inner gravisphere, and it is this concept we have in mind when we talk of gravispheres in the following: The (inner) gravisphere of the earth extends to 1.5 million km (1 million mi), which is four times farther than the moon. Beyond this distance the gravitational field of the sun becomes predominant and a space vehicle becomes a satellite of the sun, or planetoid. Table III shows the radii of the satellite spheres of all the planets. They grow in size as a function of the mass of the planets and of their distances from the sun, because solar gravity becomes weaker with increasing distance. The sun's gravisphere extends to about half the distance to the nearest stars, i.e., 2 light years.

The moon's gravisphere reaches to 60,000 km (36,000 mi) from its center. When a rocket crosses this earth-moon gravitational divide it can, if properly guided in direction and controlled in velocity, become a satellite of the moon. The gravisphere concept clearly delineates where planetary space ends and interplanetary and interstellar space begins. It is also useful for a better understanding of the first, second, and third astronautical or cosmic velocities.

The first astronautical velocity is the orbital velocity. The circumterrestrial circular velocity near the earth's surface amounts to 8 km (5 mi) per second. With increasing altitude the orbital velocity decreases and the period of revolution of the satellite increases correspondingly, which is of interest medically.

Table IV shows the orbital characteristics (velocity and period of revolution) of earth satellites in freely selected altitudes beginning above the mechanical border of the atmosphere. The orbits are projected against the topography of the Van Allen radiation belt and accordingly subdivided into 3 groups: those below the Van Allen Belt (low orbits), those within the Van Allen Belt (medium orbits), and those above this belt (high orbits).[24, 25]

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The arena for manned satellite flight will be confined to low orbits, not higher than 800 km (600 mi). The middle orbits reaching up to the outer border of the outer zone of the Van Allen radiation belt, around 15 earth radii, are presently the forbidden orbits for manned satellite flights unless suitable shielding can be provided. In high orbits a satellite vehicle would be exposed solely to the general omnidirectional flux of energetic particles and, of course, to the temporal dangerous winds of solar plasma. This shows us the importance of a combined consideration of some ecological conditions and gravitational motion-dynamics in space. Knowledge of the orbital flight characteristics also informs us how long a satellite vehicle travels through the shadow of the earth, or is exposed to solar electromagnetic radiation, which we discussed earlier.

Similar combined ecological and gravitational considerations can be applied to circumnavigation of the moon with the exception that the moon has no radiation belt. This can be concluded from the Russian recordings of the magnetic field of the moon which is 400 times weaker than that of the earth. Consequently manned satellite flight around the moon would not be confined to certain altitude levels. The circum-lunar orbital velocity near the surface is 1.6 km per sec (1 mi per sec), and one period of revolution takes

1 hour and 48 min. Table V shows the characteristics of lunar orbits in freely selected altitudes. At 1000 km altitude it takes 3 1/2 hours and at 20,000 km more than three days to orbit around the moon. Again the moon's shadow has to be considered in such circumlunar operations. So much about the orbital velocities and their relation to the exposure of a space vehicle to the various ecological space factors.

The second astronautical velocity is the escape velocity which carries a space vehicle besides to the moon, beyond the earth gravisphere into interplanetary space with its various radiation conditions which we discussed earlier and other factors which will be discussed in other lectures. The third astronautical velocity which is the escape velocity from the sun's gravisphere leads us into interstellar biophysical problems. This, however, is beyond the scope of this lecture, which is confined exclusively to the biophysics of the space within our solar system.

2

## ANNEX

### Photometric Terms and Units

| | |
|---|---|
| Illuminance: | Luminous flux incident on unit area. Unit: Lux, foot candle. |
| Lux (lx): | Synonym metercandle: An illuminance of one lumen per square meter. |
| Foot Candle (ft-c): | Illuminance of one lumen per square foot. |
| Lumen (lm): | The luminous flux emitted through a unit solid angle (one steradian) from a point source of one candela. |
| Luminance: | (photometric brightness): Luminous intensity of any surface in a given direction per unit projected area of the surface viewed from that direction. Unit: nit. |
| Nit (nt): | A luminance of one candela per square meter. |
| Candela (cd): | Unit of luminous intensity. New defined and internationally accepted candle. |

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TABLE I

SOLAR IRRADIANCE FROM MERCURY TO PLUTO

| | Distance from Sun $10^6$km | Intensity Factor | Irradiance cal/cm$^2$ min | Illuminance lux |
|---|---|---|---|---|
| | 30 | 24.8 | 49.7 | 3,480,000 |
| | 40 | 13.97 | 27.9 | 1,960,000 |
| Mercury | 46.0 | 10.57 | 21.1 | 1.480,000 |
| Mercury | 57.9 | 6.67 | 13.3 | 935,000 |
| Mercury | 69.8 | 4.59 | 9.18 | 643,000 |
| | 80 | 3.49 | 6.99 | 489,000 |
| | 100 | 2.24 | 4.47 | 313,000 |
| Venus | 108.2 | 1.91 | 3.82 | 267,000 |
| | 130 | 1.322 | 2.64 | 185,000 |
| Earth | 147.1 | 1.034 | 2.07 | 145,000 |
| Earth | 149.6 | 1.000 | 2.0 | 140,000 |
| Earth | 152.1 | .967 | 1.935 | 135,000 |
| | 180 | .690 | 1.380 | 96,600 |
| Mars | 206.6 | .524 | 1.047 | 73,300 |
| Mars | 227.9 | .431 | .861 | 60,300 |
| Mars | 249.2 | .360 | .720 | 50,400 |
| | 300 | .248 | .497 | 34,800 |
| | 500 | .0894 | .179 | 12,500 |
| Jupiter | 778.3 | .0369 | .0739 | 5,170 |
| | 1000 | .0224 | .0447 | 3,130 |
| Saturn | 1428 | .01096 | .0219 | 1,530 |
| | 2000 | .00559 | .0112 | 782 |
| Uranus | 2872 | .00271 | .00542 | 380 |
| Neptune | 4493 | .00111 | .00222 | 155 |
| Pluto | 5910 | .000640 | .00128 | 90 |

2

TABLE II

SHADOW CONES IN SPACE

| | Distance from Primary | | Length of Shadow Cone | |
|---|---|---|---|---|
| | AU | $10^6$ km | AU | $10^6$ km |
| Mercury | .39 | 57.9 | .00135 | .202 |
| Venus | .72 | 108.2 | .00663 | .992 |
| Earth | 1.00 | 149.6 | .00926 | 1.385 |
| Mars | 1.52 | 227.9 | .00747 | 1.118 |
| Jupiter | 5.20 | 778 | .607 | 90.8 |
| Saturn | 9.55 | 1428 | .908 | 135.9 |
| Uranus | 19.2 | 2872 | .68 | 101.8 |
| Neptune | 30.1 | 4498 | .99 | 148.1 |
| Pluto | 39.5 | 5910 | .41 | 61.8 |

TABLE III

RADII OF PLANETARY GRAVISPHERES

| | | |
|---|---|---|
| Mercury | 0.22 | Million km |
| Venus | 1.0 | " " |
| Earth | 1.5 | " " |
| Mars | 0.5 | " " |
| Jupiter | 53 | " " |
| Saturn | 65 | " " |
| Uranus | 70 | " " |
| Neptune | 116 | " " |
| Pluto | 57 | " " |
| Moon | 0.060 | " " |

## TABLE IV. EARTH SATELLITES

| Altitude above Surface | Distance from Center | Distance in Units of Earth's Radius | Distance in Percents of Radius of Earth's Gravisphere | Speed in Orbit | Period of Revolution (sidereal) | Altitude above Surface |
|---|---|---|---|---|---|---|
| km | km | -- | % | km/sec | days hr min | miles |
| 0 | 6,371 | 1 | .425 | 7.909 | 1 24 | 0 |
| 100 | 6,471 | 1.016 | .431 | 7.848 | 1 26 | 62 |
| 200 | 6,571 | 1.031 | .438 | 7.788 | 1 28 | 124 |
| 300 | 6,671 | 1.047 | .445 | 7.729 | 1 30 | 186 |
| 400 | 6,771 | 1.063 | .451 | 7.672 | 1 32 | 249 |
| 500 | 6,871 | 1.078 | .458 | 7.616 | 1 34 | 311 |
| 600 | 6,971 | 1.094 | .465 | 7.561 | 1 37 | 373 |
| 700 | 7,071 | 1.110 | .471 | 7.507 | 1 39 | 435 |
| 800 | 7,171 | 1.126 | .478 | 7.455 | 1 41 | 497 |
| 900 | 7,271 | 1.141 | .485 | 7.403 | 1 43 | 559 |
| 1,000 | 7,371 | 1.157 | .491 | 7.353 | 1 45 | 621 |
| 1,500 | 7,871 | 1.235 | .525 | 7.116 | 1 56 | 932 |
| 2,000 | 8,371 | 1.314 | .558 | 6.900 | 2 07 | 1,243 |
| 3,000 | 9,371 | 1.471 | .625 | 6.521 | 2 30 | 1,864 |
| 5,000 | 11,371 | 1.785 | .758 | 5.920 | 3 21 | 3,107 |
| 10,000 | 16,371 | 2.570 | 1.09 | 4.934 | 5 47 | 6,214 |
| 20,000 | 26,371 | 4.139 | 1.76 | 3.888 | 11 50 | 12,427 |
| 35,868 | 42,239 | 6.630 | 2.82 | 3.072 | 1 00 00 | 22,287 |
| 50,000 | 56,371 | 8.848 | 3.76 | 2.659 | 1 13 00 | 31,069 |
| 70,000 | 76,371 | 11.987 | 5.09 | 2.385 | 2 07 54 | 43,496 |
| | 100,000 | 16.70 | 6.67 | 1.996 | 3 15 26 | |
| | 150,000 | 24.54 | 10.0 | 1.630 | 6 16 37 | |
| | 200,000 | 32.39 | 13.3 | 1.412 | 10 07 | |
| | 300,000 | 48.09 | 20.0 | 1.153 | 18 22 | |
| | 384,405 | 60.33 | 25.6 | 1.018 | 27.3 | |
| | 500,000 | 79.48 | 33.3 | .898 | 40.5 | |
| | 700,000 | 110.9 | 46.7 | .759 | 67.1 | |
| | 1,000,000 | 158.0 | 66.7 | .635 | 114.5 | |
| | 1,500,000 | 236 | 100 | .519 | 210 | |

## TABLE V. MOON SATELLITES

| Altitude above Surface | Distance from Center | Distance in Units of Moon's Radius | Distance in Percents of Radius of Moon's Gravisphere | Speed in Orbit | Period of Revolution (sideral) | Altitude above Surface |
|---|---|---|---|---|---|---|
| km | km | -- | % | km/sec | days hr min | miles |
| ( 0 | 1,738 | 1 | 2.85 | 1.679 | 1 48 | 0 ) |
| ( 10 | 1,748 | 1.0058 | 2.87 | 1.675 | 1 49 | 6.2) |
| 30 | 1,768 | 1.017 | 2.90 | 1.665 | 1 51 | 31.1 |
| 100 | 1,838 | 1.058 | 3.01 | 1.633 | 1 58 | 62.1 |
| 200 | 1,938 | 1.115 | 3.18 | 1.590 | 2 08 | 124.3 |
| 500 | 2,238 | 1.288 | 3.7 | 1.480 | 2 38 | 311 |
| 1,000 | 2,738 | 1.575 | 4.5 | 1.338 | 3 34 | 621 |
| 2,000 | 3,738 | 2.151 | 6.1 | 1.145 | 5 42 | 1,243 |
| 5,000 | 6,738 | 3.877 | 11.0 | .853 | 13 47 | 3,107 |
| 10,000 | 11,738 | 6.754 | 19.2 | .646 | 1 7 42 | 6,214 |
| 20,000 | 21,738 | 12.5 | 35.6 | .475 | 3 7 54 | 12,427 |
| (59,000 | 61,000 | 35.1 | 100 | .283 | 15 16 | 37,000 ) |

3

LECTURES IN AEROSPACE MEDICINE

# CELESTIAL BODIES--THE SUN

Presented By

Professor Walter Orr Roberts

Director, University Corporation

for Atmospheric Research

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# Celestial Bodies -- The Sun

by

Walter Orr Roberts

## The Sun Among the Stars

The sun provides man a unique insight into the basic life-sustaining processes of the universe: the energy production in a star. Of some thousand billion billion stars within range of today's most powerful telescopes, the sun is the only one close enough to show its surface as more than a mere pinpoint of light.

This proximity is, of course, no accident. Or perhaps I should say it the other way around; it is no accident that we exist on a planet so close to the surface of a star, for if we were not so favorably near, our planet could not begin to sustain any form of life even remotely resembling ours. The nearest other star is some 200,000 times farther away than the sun, and many bright stars of the night sky are tens of millions of times farther away than the sun. This makes the prospect mighty slender for sending space vehicles there, though there seems to be an outside chance that we may some day establish radio contact with the inhabitants of a planet circling one of the closer stars.

Proximity enhances our ability to understand the sun, which is an undistinguished version of one of the commonest kinds of stars, but which, by virtue of the fact that it is indeed a star, tells us something about the entire universe of stars. The sun is yellowish in color, compared

to the generally brighter and more massive bluish stars, or alternatively compared with the fainter, smaller stars that are generally more reddish in color.

All stars are giant nuclear energy machines. Each second of time the sun converts some four million tons of its matter into its radiant output to space, some one billionth of which falls upon the earth. One second of time the sun's rate of nuclear energy production would supply man's present level of power needs for over a billion years. Yet this prodigious output of energy is depleting the sun's fuel resources at only a modest rate, and we can probably count on no major changes in the solar heat output for billions of years to come.

The sun, under close scrutiny with today's powerful array of specialized telescopes, reveals a wealth of information about which has developed a whole field of scientific research. The largest portion of the sun's radiant output is accounted for by pointing out that the sun closely approximates a perfect spherical radiator with a diameter of 1,390,000 kms and a surface temperature of 6000° K. This means that it radiates a total energy of about $3.9 \times 10^{33}$ ergs per second. Seen from the earth, the sun's disk subtends an angle of approximately one-half degree, almost precisely the angular size of the much closer moon, a happy accident for total eclipse photographers.

The internal temperature of the sun can be inferred to be about 20 million degrees K. The entire body of the sun, from core to surface

is gaseous, and the principal constituent gas is hydrogen. At the core, the weight of the overlying layers of gas compresses the gas so powerfully that it reaches a density over a hundred times that of water. There, in the dense hot core, nuclear processes gradually convert the hydrogen of the sun's mass to helium. Only a small percent of the helium supply has been consumed in the estimated four billion years of past history of the sun.

A striking fact about the sun is its steadiness as a heat source. Many stars fluctuate wildly. The sun does not. Its total energy variations are as yet not securely detected at all, and they are certainly less than a one percent energy change from one day to the next or from one year to the next. The observed steadiness rules out any simple explanation of major terrestrial weather changes from year to year in terms of brute force changes in the intensity of the sunlight falling on the earth. The steadiness, of course, is a good thing for man, for even small variations of a few percent would have the effect of making the conditions of life on earth more variable and thus more difficult.

The close-up view of the sun, however, reveals a wealth of detail and subtler changeability. And to a space traveler this variability may be a far more important fact than the rigorous uniformity of the total energy output of the sun. In the space environment, beyond the protective shield of earth's gaseous mantle, man's concern about solar variability will shift to the extreme short wavelength regions of the spectrum and to the sun's output of charged particles. Here he will find powerful levels of penetrating, damaging radiation. An the variability of these emissions

ranges over enormous factors in periods of time measured in minutes or hours.

These violently changing radiations appear to be connected to variations of certain of the visible features of the sun. But the exact nature of the physical connections is very much of a mystery right now. Perhaps the greatest challenge in astrophysics today is to explain in detail the relation of the observed solar features to the multitude of phenomena of the fluctuating radio, particle and shortwave emissions of the sun. This is indeed a prime objective of the High Altitude Observatory and its sister institution, the Sacramento Peak Observatory of the Air Force Cambridge Research Laboratories. It is likewise a central goal of other observatories both here and abroad.

## Sunspots and Flares

The surface of the sun, when viewed in a telescope of modest size, appears at first glance to be a luminous disk of smoothly varying brightness, slightly more brilliant at the center than near the edges. This disk, the "photosphere" of the sun, is the layer of the sun that defines its gaseous surface. At this level, just a few tens of kilometers change the gases from essentially transparent to essentially opaque gases, for all wavelengths of visible light.

On closer examination, however, the sun's disk reveals a structure of great complexity and interest. Most noticeable are the large sunspot groups that dot the surface irregularly. These change rather irregularly in size and complexity, but have exhibited more or less regular overall

"sunspot cycle" of average activity. The length of the sunspot cycles has averaged, since the year 1750, about 11.4 years, counting from the minimum of one fluctuation to the minimum of the next. The range of fluctuations of the area of sunspots on the disk is by large factors. In some years sunspots have been extremely rare, and when present generally have been small. Such a period came around 1800 to 1825. At other times, as in recent years, the sun's disk has frequently been covered with over a hundred spots, some large, some small, and generally gathered together in great clusters in the major "sunspot regions." Christmas Day of 1957 reached the highest sunspot number of any date since telescopic observations were commenced, back at the time of Galileo, around 1612. The peak of average solar activity was reached in 1957, during the International Geophysical Year; the 1957 average sunspot number was the largest since 1778.

Sunspots not only vary in number and size from day to day but can also be detected drifting from east to west as the sun rotates on its own internal axis. A rotation at the equator takes something like 26 days, judged by the sunspot motion, but takes a bit longer near the sun's rotation axes at the north and south poles. Sunspots are rarely found, however, at solar latitudes higher than about forty degrees, and the rotation period at higher latitudes must be determined by other means. Large sunspot groups are obviously symptoms of deep seated regions of great activity. Such regions can often be traced through several solar rotations, spending about two weeks in each passage across the sun's face.

Individual large sunspots run about 1500° Kelvin cooler than the surrounding surface of the sun. Moreover, they exhibit enormously complex structure, with the dark center or "umbra" surrounded by regions of filamentary grey areas, the "penumbrae", which are intermediate in brightness between the umbra and the surrounding surface. The penumbrae generally exhibit a structure directed radially towards the center of the sunspot. Sometimes there are indications of vorticity in penumbrae. There are also indications of large scale organization in the filamentary threads that lie within confines of the large sunspot region and that interconnect the different individual spots and groups of the region.

Outside the sunspot areas the solar surface possesses a distinctive mottling, the "granulation", with individual cells possessing extremely small sizes of the order of a few hundred kilometers in largest dimension. These cells show clearly polygonal outline of their bright areas, which appear relatively large in size compared to the darker interstices between. Figure 1 illustrates a complex sunspot group photographed with a telescope capable of magnificently high resolution, from a balloon operated in the stratosphere by Dr. Martin Schwarzschild and his colleagues at Princeton University Observatory.

The principal clue to the physical nature of the sunspots and their associated active regions is probably to be found in the large magnetic fields that can be detected by the Zeeman effect in sunspots and surrounding regions. It is not unusual for a major sunspot to exhibit a magnetic field strength of several thousand gauss. Moreover, the individual spots of a sunspot region sometimes exhibit extraordinary complexity of magnetic field structure, with some sunspots showing large field, others small, some

positive field orientation, others negative. It is a general rule that major sunspot groups tend to develop into two principal centers of reversed polarities, suggesting that spot groups as a whole could roughly be approximated by a huge horseshoe magnet lying buried beneath the solar surface. In an entirely gaseous medium, of course, the origin of the magnetic forces must be explained in terms of powerful current systems. However, the details of the explanation of the field have thus far eluded the astrophysicist.

The most violent and abrupt of solar activity phenomena are the brilliant solar flares that frequently appear in complex sunspot regions. These flares are intense brightenings at or near the solar surface, visible in the light of the strong lines of the spectrum of hydrogen gas. It is clear that flares are regions of intensely compressed gas which are elevated to much higher temperatures and which emit powerfully in the emission lines of hydrogen and other abundant constituents of the sun such as helium, calcium, iron, sodium, etc. Flares sometimes rise to maximum brightness in periods as short as one-half minute. Generally speaking the rise to maximum brightness is abrupt, usually measured in just a few minutes, and is followed by a more gentle decline of the region of flare brightness back to the intensity of the undisturbed surface. The decline may take as much as a few hours in some instances.

Flares can produce large changes in the radio, ultraviolet, X-ray, and particle emissions of the sun. The effects of such emissions are a major factor that future astronauts must face in travels through the solar system. We are protected on earth from these emissions because they

are absorbed in the earth's upper atmosphere. The very process of absorption produces a host of ionospheric and other upper atmospheric effects of considerable significance and interest. Among these are sudden fade-outs of long distance, shortwave radio communication, due to increased absorption in the lower levels of the ionosphere; enormous increases in proton bombardment in the polar caps of the earth; brilliant displays of the Aurora Borealis and Aurora Australis; disturbances of the direction and strength of the earth's magnetic field; and powerful beams of meter-length solar radio radiation that interfere with low-power radar and other radio frequency operations, at times. Table 1 gives an estimate of the nature and degree of variability of some of the changeable solar emissions associated with different kinds of variations of the sun. Many of these variations have a marked relationship with solar flare emission, but there are many subtle unknowns in the inter-connection, and there is no proportionality between flare brightness and the intensity of the emissions received at earth.

The particle emission of the sun in particular has complex and subtle relationships to solar flares and to other aspects of solar variability. For example, the bombardment of the earth's polar regions by solar protons seems to be somewhat more effective when the associated flare and sunspot region are located in the western half of the sun's visible disk, as viewed from the earth. This suggests that the shape of the magnetic fields lying in space between sun and earth has an influence

on the paths of the protons in their transit of the intervening 90 million miles, which they accomplish in some one to two hours generally. There are also interesting variations in the frequency of Aurora Borealis that imply a connection with solar variability that is not directly related to flares or to sunspots. There is a peak, for example, in the frequency of occurrence of auroras that develop in the post maximum phase of the sunspot cycle as sunspot activity is declining towards minimum. Series of auroras will frequently materialize at 27 day intervals, at such times, presumably in response to the 27-day rotation of the sun, but not showing any definite relationship to any observable sunspot groups. Moreover, there are well known peaks in the annual frequency of auroral and geomagnetic disturbance in spring and in fall, and it seems clear that the explanation for this is not to be found in any internal physical processes of the sun.

Chromosphere

Directly above the solar photosphere the temperatures of the sun's atmosphere, which can be considered to commence at the photosphere, rises. At the same time, the transparency of the atmosphere increases abruptly, particularly in the continuous spectrum of the sun, outside the strong spectrum lines of the solar constituents. This layer of the atmosphere is enormously important in the understanding of the sun's emissions outside the visible and near-visible range (3,000 to 30,000 A.)

A great deal of attention has been given this range of the solar atmosphere, since large differences in intensity occur for wavelengths at the centers of different spectrum lines, and these physical factors hold

clues to the detailed physical state of the atmosphere at just the levels where a large part of the "anomalous" variable solar radiation originates. In general it is necessary to consider physical processes relevant to non-equilibrium states of the gases, with sources and sinks of radiation, kinetic energy, magnetic field energy all carefully examined.

The realm of the chromosphere is so small in height (about 15,000 km at most) so that observations of it are extremely difficult. For this reason it is still highly important to conduct expeditions to total solar eclipses at which it is easier to resolve chromospheric details without the hampering effect of strongly scattered photospheric light.

## Prominences and Corona

Turning away from the features of the solar surface or photosphere, we find the sunspot regions and regions of the solar disk to be overlaid by an atmosphere of astonishing complexity when it is appropriately viewed. The best opportunity to view the solar atmosphere, until recent years, has come at total solar eclipses, when the phenomena of the atmosphere are magnificently revealed for brief periods within the path of totality. However, astronomers have pursued vigorous efforts, for many years, to develop means for viewing the eclipse features of the sun without natural eclipse. Specialized telescopes have been developed for this purpose and are in operation at numbers of observatories, now, throughout the world. Figure 2 shows a region at the edge of the sun photographed in the light of one of the gaseous constituents of the sun's atmosphere, highly ionized iron gas of the sun's "corona." The temperature of the gas shown is measured in millions of degrees, and the atoms involved are highly stripped atoms of iron, which testifies to the enormously great ionization

that takes place near the solar surface and to the low density of the solar atmosphere. The gases shown in this figure are at lower pressures than good laboratory vacua, and the complex structure almost certainly outlines the magnetic field in which the gas is imbedded. Such gases must be predominantly controlled by the magnetic field of the atmosphere because the magnetic field energy density greatly exceeds the thermal or kinetic energy of the gas.

Figure 3 shows another striking feature of the solar atmosphere, a large solar prominence. Prominences are considerably lower in temperature than coronal features, and are observed in entirely different gases. It is evident that the prominence materials thread the same general volumes of space as the corona, but it is suspected that the individual filaments of prominence gas are denser and at lower temperature than the surrounding corona. The characteristic motions of the corona and prominences magnificently revealed in cinematographic studies, which display enormous differences between the prominences and corona in their motions.

Great progress has been made in recent years in developing an understanding of the physical processes that work in the solar atmosphere, but there are many unexplained mysteries left for future workers. It is clear that when solar flares occur in or near the solar surface, great changes frequently develop in the coronal and prominence regions directly above. On some occasions giant clouds of gaseous particles are accelerated to high speeds and ejected bodily from the solar atmosphere. At other times it seems clear that plasma clouds, made up of ions of solar gas, are reflected by the magnetic field, and trapped in the solar atmosphere much

as the Van Allen particles are trapped in the terrestrial atmosphere. When this occurs, powerful radio radiations are sometimes observed at the earth, emanating from the active regions of the solar atmosphere. It is suspected that this radiation is of nature similar to that generated by the interaction of particles and magnetic field in synchrotrons and cyclotrons in terrestrial laboratories. In some instances the acceleration of particles in the sun's atmosphere produces powerful beams of cosmic rays. For example, a major flare on 23 February 1956 produced a many-fold increase in the background cosmic ray intensity observed at stations all over the world. Such cosmic ray bursts, though rare, will be of no mean consequence to future astronauts.

Solar-Terrestrial Research and Space Environmental Physics

Research concerning the influences of solar particles on the upper atmosphere of the earth has enormous relevance to our understanding of the environment in which man must live when he ventures into space. Supplanting the simple picture that physicists had some few years back, in which an essential vacuum permeated the space between sun and earth, we have today a far more complicated story. We visualize the solar atmosphere as extending continuously from the photosphere of the sun to beyond the reaches of the farthest planet. This atmosphere exhibits complex structure, is interlaced with magnetic fields of various orientations, occasionally is cannonaded by powerful plasma clouds which tear up the magnetic field in their passage, and is punctuated at intervals by blasts of X-ray and ultra-violet radiation. These are harmless to man when he lives on earth because of the atmospheric shield of the first few

hundred kilometers of the terrestrial atmosphere. The heat of solar radiation, the principal energy supply for earth, penetrates this atmospheric shield and provides sustenance for man's activities.

In space, however, man is subjected to quite different environmental circumstances. The total energy falling on his capsule in the form of visible light is relatively unchangeable. But his capsule will be blasted by other radiations to which his body is highly sensitive, even though the total energy of such radiations is small. The key to understanding the physics of these radiations, and thus to their variations and distributions in space will be found in solar and solar-terrestrial research to be accomplished in the years immediately ahead. The earth's atmosphere is a magnificent laboratory in which to study the changeable nature of these impinging radiations. The earth's magnetic field affords a superlative device for separating out different forms of particle emissions and for collecting electrified particles over volumes of space much larger than would otherwise be possible.

Moreover, the other planets besides earth offer important possibilities for further refining our understanding of the sun's emissions and influences on the space environment. Recent studies, for example, have shown that powerful radio emissions are frequently generated in the Jupiter atmosphere. Figure 4 shows, for example, radio noise emission detected in the atmosphere of Jupiter by Dr. James W. Warwick of the High Altitude Observatory. It can be seen that the blocks of Jupiter radio emission tend to concentrate at times of increased solar activity or at times of heightened

terrestrial magnetic activity, which is in turn sun-induced. The physical conditions of Jupiter's atmosphere and the characteristics of Jupiter's magnetic field are undoubtedly drastically different from those of earth. Jupiter has an entirely different rotation period from the earth, and because of these differences it seems very promising that substantial basic knowledge about the sun's emissions will come from study of their effects upon the planet Jupiter. The powerful tools of solar-terrestrial research will thus be enhanced by the added prospects of study of the atmosphere of Mars and the other planets. Already a substantial body of material is developing under the awkward name of solar-Jovian relationships.

Finally, it must be recognized that in the last analysis there will be many observations for which the only direct knowledge must come from instruments actually flying in space. Enormous progress has already been made, as everyone knows, in the development of satellite research. Space probes have conveyed to us simple but vital information. It seems certain that the near future will bring more sophisticated space probes. Their results, coupled with the development of fundamental theory of the solar atmosphere and the study of the influences of the solar emissions of the atmospheres of the various other planets will lead man securely towards an understanding of the hazards space travelers must avert in their adventures beyond the protective shield of the atmosphere.

FIGURE 1

A large sunspot group photographed on 17 August 1959 by M. Schwarzschild and collaborators from a balloon at 80,000 feet altitude. Note the dark umbra, the radially organized filamentary penumbrae and the polygonal granulations. (Project Stratoscope of Princeton University, sponsored by the U.S. Office of Naval Research and the U.S. National Science Foundation)

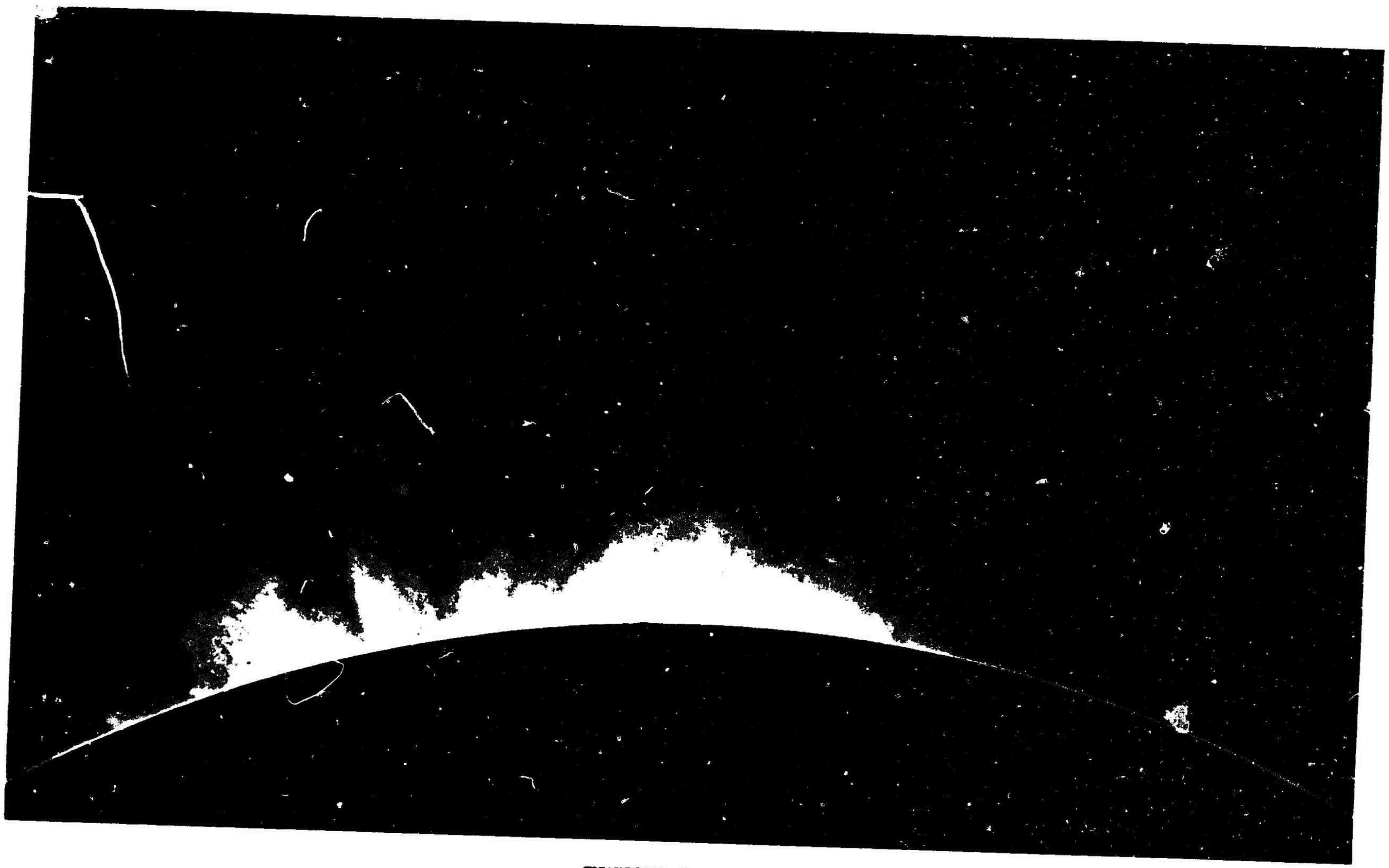

FIGURE 2

A photograph of the sun's corona in the light of FeXIV (5303A) taken with the coronagraph of the Sacramento Peak Observatory, Geophysics Research Directorate. AFCRL.

FIGURE 3

A solar prominence at the sun's edge photographed in the light of hydrogen gas. The curved loops reveal the structure of the magnetic field in which the gases are moving. (Sacramento Peak Observatory, Geophysics Research Directorate AFCRL.)

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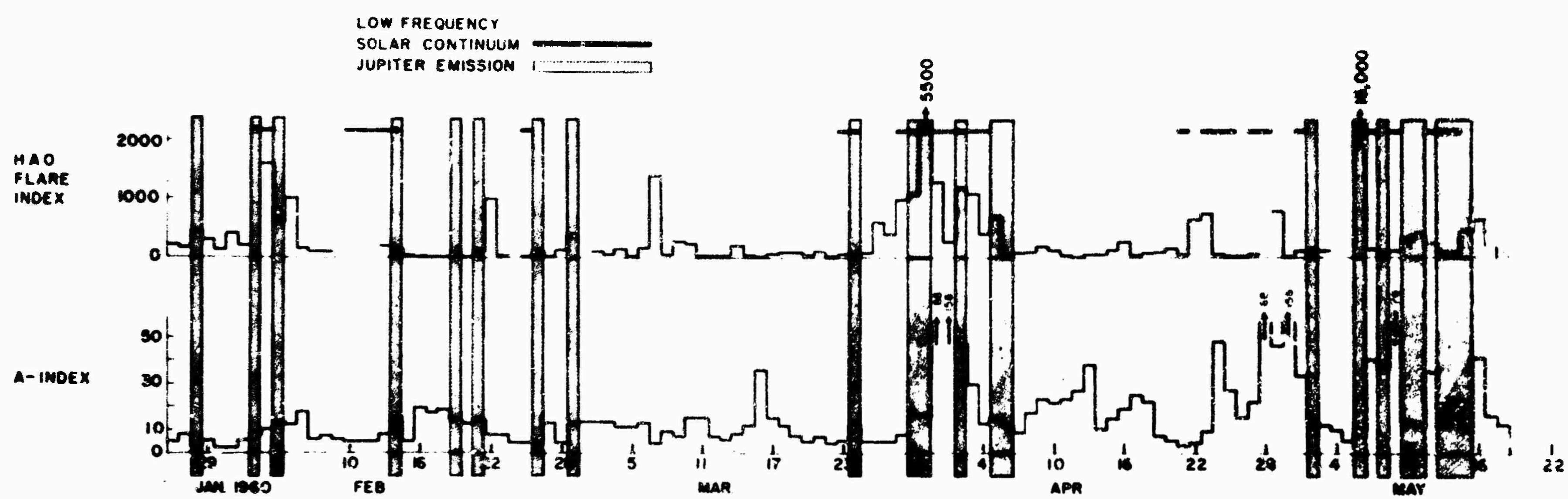


FIGURE 4

Diagram showing solar flare activity (upper graph) and terrestrial magnetic fluctuations (lower graph of A-index) on dates in early 1960. Shaded blocks represent periods of strong Jupiter atmospheric radio emission at low radio frequencies. Solid lines at top represent solar radio nosie emission. Note that periods of strong solar and geomagnetic activity tend to associate with strong Jupiter radio noise.

Table I

Sun's Emissions

| Nature of Process | Wavelength | Representative Flux at Earth, ergs $cm^{-2}$ $sec^{-1}$ | Magnitude of Variations |
|---|---|---|---|
| Radio waves | 0.1 cm-30 meters | $3 \times 10^{-7}$ | $\times 10^3$ |
| Infrared radiation | 3-600μ | $3 \times 10^4$ | Very small |
| Optical radiation | 300-30,000 Å | $1.4 \times 10^6$ | Very small |
| Near ultraviolet | 1500-3000 Å | $2 \times 10^4$ | Very small |
| Lyman-ultraviolet | 1216 Å | 5 to 10 | x 3 |
| Far ultraviolet | 10 Å-1000 Å | 1 (?) | Large |
| Soft x-rays | 1-10 Å | $10^{-3}$ to $10^{-4}$ | Large |
| Hard x-rays and γ-rays | 1 Å | Uncertain | Large |
| Particles (corpuscular emission) | Protons and electrons of $10^4$ to $10^5$ ev | $10^4$ (and possibly up to $10^6$) ergs $cm^{-2}$ $sec^{-1}$ over small areas in auroral zone; enormous variations | |
| Thermal conduction | Values are uncertain, but temperature of interplanetary gas, on simplified models, in the Earth's environs as high as $10^5$ may be possible; variations are probably large | | |

LECTURES IN AEROSPACE MEDICINE

THE MOON

Presented By

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Research Center

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# THE MOON

by

Clyde W. Tombaugh

The moon is the most readily observed of all celestial objects. It is close, large, and not too bright. Without an atmosphere of its own, its surface is nakedly exposed to view. To the unaided eye, several dark areas and bright spots are easily visible on the moon's disk, which sparked the concept of other worlds to the earliest philosophers. Man has long dreamed of going to the moon, not realizing the hostile conditions that prevail on this world.

If man is to survive in the exploration of planetary worlds, he must observe and study every possible aspect in order to design facilities for providing the life-sustaining conditions that the planet may lack. Just one error or one oversight could be lethal. The necessary knowledge is still quite incomplete. There is still a great deal to be learned from ground based observations, which unfortunately, has not received adequate support. Other needed information can come only from space probe rendezvous, which are much more expensive.

Let us inquire into the properties of planets that determine the physical conditions on their surfaces, with particular emphasis to the moon. The moon is a secondary planet, since its immediate primary is a planet. The most important is the capacity of a planet to hold an

atmosphere. The mass and radius determine the force of gravity; while temperature and molecular weight set the pace of movement of gaseous molecules. If gravity is too weak, a gaseous substance will gradually escape from a planet. This has most important consequences upon the meteorology and geology, and in turn, upon the biological conditions on a planet.

The force of gravity on the surface of the moon is only one-sixth of that prevailing on the Earth. Consequently, the angle of repose should be much steeper for piles of loose debris and lava flows. One would have to go six times deeper into the moon's crust to experience a corresponding pressure, and rock will flow to an isostatic equilibrium when the pressure becomes great enough. If other factors, (such as radioactive heating) are equal, the moon's crust should be six times thicker than the Earth's crust. This should increase the strength of the crust many times which would offer much greater resistance to crustal readjustments. Greater stresses would build up before the yielding points were reached, resulting in less frequent but more severe moonquakes. However, the lack of water erosion to shift the crustal loads may result in even fewer moonquakes. The interior slopes of one great class of craters, the "ringed plains," are gentle, ten degrees or less. These are the ones that exhibit the features of impact craters. The crushed

rock debris appears to have been shaken down from the expected steep angles of repose. Quite likely this was accomplished by the severe jars of later impacts.

There are other very interesting consequences on a world of lesser gravity. The volatile constituents of magmas would not be as readily squeezed out, because of the reduced gravitational pressure. The congealed magmas would be much more vesicular in texture, and porosity in rocks would extend to depths six times as great. It has been suggested that an appreciable amount of free water may exist in vesicles not far below the surface where the temperature remains constant and is comparable to that of our mean annual sub-surface. The Earth and the moon are at the same distance from the Sun, essentially. Especially in regions of high latitude, there may be deposits of perma-frost below the surface.

Also, rocks would not be compacted to the degree they are on the Earth, resulting in less density for the same material. Segregation of heavier minerals in a magma would be less effective, thus tending to produce less variety in igneous rocks. These conditions may have favored the formation of rock more largely composed of hydrous minerals, such as serpentine and chlorite. Many substances seem able to entrap water in their surface layers, if formed or crystallized in contact with water.

The Earth has had such an entirely different geological history that it is extremely difficult to predict what the lunar surface material may be like.

Dr. Spurr has invented new names which are appropriate. He refers to the light-colored materials of the lunar highlands as "lunarite", and the darker material of the maria as "lunabase".

Another vast difference between the Earth and the moon is the absence of atmospheric weathering on the moon. This important agent consists of two types of action, chemical and mechanical. Oxygen is extremely active in combination, and half of the mass of the Earth's crust is composed of oxygen atoms. How much is of primary combination and how much is secondary is obscured by the many cycles of rock destruction and re-making throughout the long ages of geologic history. Indeed, the remains of shell life in fossiliferous limestones, form rock beds of considerable thickness. Water has played a most significant role, both chemically and mechanically. So much of the Earth's land surface is covered by sedimentary beds that were laid down in the sea in various periods of the past, many of which were almost eroded away in places in later times, that we are greatly impressed with the importance of abundant water in shaping our world. There is much evidence that none of this occurred on the moon, nor on Mars and Mercury - all because the force of gravity on these worlds was not strong enough to retain the high speed lighter molecules of the atmosphere. The absence of any perceptible twilight at the cusps of the crescent moon indicates that the moon cannot have an atmosphere greater 1/100,000 that sea-level on the

Earth. Theoretical values have made it even less. The velocity of escape of gaseous molecules on the Earth is 11.19 kms per sec, but on the moon, it is only 2.38 kms per sec. Many surprises are in store for the first lunar explorers. There can be little doubt that the moon's surface will tell us much about the origin of the solar system and the nature of p. imeval substances. The actual exploration of the lunar world will aid us in better understanding our own.

The amount of unconsolidated debris on the moon's surface is controversial. From the Journal of the International Lunar Society, some Russian observations have been summarized by Prof. N. Barabashov, Chairman of the Soviet Commission for the Study of Physical Conditions on the moon. "From photometric, spectral, and polarization tests, it seems that the moon is covered with a layer of disintegrated tufa-like rock, with the size of the grains from 3 to 10 mm. In all probability the layer of crushed matter on the surface of the moon is not more than 3 cm. thick." (Slide 1) But, telescopic scrutiny of the moon's surface features indicate that the greater portion of the maria is not covered with even a continuous layer of pulverized debris; otherwise, the maria would exhibit a higher albedo like the areas occupied by the explosion craters and the bright rays. So the above figures must apply to some average or mean area. On the other hand, many of the large old craters on the bright mountainous highlands (Slide 2) exhibit an appearance of partial obliteration. Also, the very gentle interior slopes suggest that

the loose debris was shaken down, so that the unconsolidated material may be hundreds of feet deep in some places (Slide 3). The excellent preservation of the many clefts on the maria is proof that the material of the maria is massive and possesses strength; otherwise, the clefts would have been filled shut and destroyed by moonquakes if the maria were covered deeply with dust.

It is obvious that the maria were formed at a later epoch in the moon's history through some sort of re-melting of large areas of the moon's original crust. The maria appear to have been formed suddenly and at about the same time, which is puzzling (Slide 4). The population of craters on the maria is conspicuously less than that on the bright mountainous highlands, about ten per cent. It is very evident that the craters on the maria are "post-marian" in origin. The fewer craters on the maria indicate that most of the crater-forming activity had ceased by the time the maria were formed.

The mountain walled-plains (Slide 5) constitute a large class of craters characterized by large depressions with very little rim height above the general level of the terrain. It is interesting to note that there are none found on the maria. But several large mountain "ring-plains" are found on the maria (Slide 6). The latter are characterized by central peaks and considerable rims protruding above the general level of the surrounding terrain. They are conspicuously bright under a high sun and

are attended by a bright nimbus or a system of radial bright rays. They appear to have been the scenes of great violence, as would be expected from the impact of an asteroid. Such a collision would pulverize the country rock and render it more highly reflective (Slide 7). On the old mountainous highlands, the ring-plains dominate the scene with their dazzling brilliance under a high sun and all but mask the neighboring walled-plains.

The freshest-looking ring-plains have radial systems of bright rays which run to distances of several hundred to one thousand miles from the central crater. The rays are among the most conspicuous features visible at the time of full moon. But they are not as prominent under a low sun and show no appreciable terrain relief. They are perhaps the most puzzling of all the lunar features. What agent or force could form such a remarkable pattern? Some investigators have explained the origin of a bright ray system as debris splashed out from a great explosion, in which blobs of it dribbled down as a trace of the trajectory in traversing the airless moon. But the rays do not fan out in azimuth as they recede from the central crater (Slide 8). Many of the rays are quite continuous and it is difficult to imagine the dribbling to be so perfectly distributed. Many of them are parallel twins.

I have studied these curious bright ray systems through powerful telescopes for over 30 years under conditions of high sun and low sun

illuminations, and also in the Earth-lighted lunar night side. About 15 years ago, I noticed that the so-called oasis-canal systems on Mars are remarkably similar in pattern (Slide 9). They have the same global dimensions, they are arcs of great circles on the surface of a sphere and maintain the same linearity; also they exhibit the same types of embochure with the central spot, and some are parallel doubles. There is one outstanding difference, the systems on Mars are dark, those on the moon are bright. But Mars has an atmosphere that would prevent pulverized debris from travelling very far from the scene of impact. Perhaps these patterns were crustal fractures, like the radial cracks in a windshield hit by a stone. Where the fractures meet the surface, there would be long strips of shattered rock traversing the landscape. Broken rock offers a local protective haven for hardy vegetation to grow, and this is probably the reason why the oasis-canal systems on Mars are dark. Furthermore, light winds on Mars would scatter the powdered material and obliterate any bright ray system. Therefore, they must consist of something more substantial, such as deep crustal fractures. Perhaps slight amounts of water vapor leak out from the interior along these fractures, which would further favor the growth of plants on a world whose atmosphere is exceedingly dry.

Several years ago, as an experiment I filled a globular flower vase with sand, (Slide 10) then fired at it from a distance with an air rifle.

Great circle, radial fracture patterns were formed, which were quite similar to the oasis-canal and bright ray systems.

Some geologists have raised doubts that rock would fracture that way to great distances from the impact. It is well-known that rock will shatter under a sudden blow, but it will flow like thick molasses under gradually increasing great pressure, as may be seen in folded sedimentary beds exposed in road and stream cuts. Because of the mode of formation, sedimentary beds cannot have uniform strengths and properties in all directions. Whereas, igneous rocks are more isotropic and may be expected to fracture like glass.

The response of substances to impact from projectiles varies with higher and higher velocities. There are no known places on the Earth where we may study the consequences of impacts from large, high velocity asteroids. Even the large meteorite crater west of Winslow, Arizona compares only with the small craters we see on the moon, none of which have bright ray systems. The velocity involved (at least several miles per second) may have been of the right order but the asteroid was much too small. Or, it may be that the radial systems were produced only by asteroid collisions of 30 or more miles per second. It would seem necessary to have an impact with sufficient severity to fracture the crust to its very bottom in order to produce the radial systems.

It is interesting to note that the number of Martian oases, or dark spots at the hub of the so-called canal systems, are of the same order as the number of the large ring-plains on the moon. The most convincing evidence that the canal systems (Slide 11) are the result of fractures in the shape of the maria and semi-maria areas that are sharply bounded by canals. If sections of the crust lying between fractures (Slide 12) sank several thousand feet, they would produce warmer and more favorable environments. I have observed many of these canals to continue on in a straight direction beyond the intersections where escarpments occur. But no vertical displacements are seen along any of the lunar bright rays. Perhaps the combination of a crust twice as thick and twice the curvature (as compared to Mars) provided too much friction for any vertical slipping to have taken place. Thus, it is seen that one runs into the difficulty of situations which seem to be inconsistent. We do not have the opportunity to test the responses of various materials under the full scale set of conditions and forces.

Another great difference between the bodies under comparison is that the tidal disturbances on Mars are much less than those on the Earth, because Mars is farther from the sun and its satellites are very small. On the other hand, the moon has been subjected to the most severe disturbance, especially in early times when it was nearer the Earth.

Measurements of the moon's tidal bulge and theoretical extrapolations backward in time have revealed some extremely interesting conclusions that are important to our understanding of the moon. As it is fairly well known, Sir George Darwin discovered that tidal action in the Earth-moon system is slowly forcing the moon farther from the Earth. This is accomplished through the transfer of angular momentum of the Earth's spin lost by slowing down to the moon's orbit of increasing radius. Darwin carried the extrapolation backward to the point at which the month and day were equal, and then made the remarkable assumption that the moon once formed part of the Earth. Darwin's hypothesis was that the solar tides, coming in resonance with the free oscillations of the Earth, resulted in monstrous tidal bulges, one of which ultimately broke off to form the moon. But Jeffreys found that the friction engendered in the still-liquid Earth would have been too great to permit the resonance tidal bulges from ever reaching the necessary heights. Consequently, it is probably that the Earth and moon are twin progeny, born nearly in contact and at the same time, but always having been separate. The moon could never have been closer than 11,000 miles and the corresponding month was then $6\frac{1}{2}$ hours long.

The Earth's day is lengthening by one second in 120,000 years, which means that the Earth's day has lengthened one hour since Cambrian times. Since that time, the moon has receded from the Earth by only 18,000 miles,

and the month has increased by only 3.3 days. Nearly 500 million years have elapsed since Cambrian times, yet this span represents only the last quarter of the Earth's geologic history. Almost all the startling changes occurred in the first quarter of geologic time or early in the Archeozoic Era.

The magnitude of the tidal bulge is a known function of the principal moments of inertia of the moon about its center. Observations of the mean inclination of the moon's equator to the ecliptic and also the amplitude of the moon's true libration in longitude yield moments of inertia which can be explained by the assumption that the moon's tidal bulge is 2,100 feet above the mean sphere. The moon's surface at the limbs is below the mean sphere so that the semi-axis aligned with the Earth is 3,140 feet or nearly one kilometer greater than the average radius in the plane of the sky. This value is much too great for the moon's present distance from the Earth. Jeffreys realized that it could well be that the excessive bulge was a fossil tide, one formed when the moon was still plastic enough to adjust its figure to the equipotential surface. At some specific distance from the Earth the moon's layers solidified to the point where compensation could no longer occur, and from that time on, as the moon receded, the primitive bulge remained as a fossil tide. It is evident that the strength of the lunar crust rocks is ample to allow the moon to maintain a permanent departure from

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hydrostatic equilibrium.

Jeffreys calculated that the moon acquired a tide of the dynamically derived height when it was at a distance of about 90,000 miles, which was reached about 65 million years after the birth of the moon.

Fortunately, photographs of the moon in various librations show that well-defined points deviate in their apparent shifting from the trigonometric foreshortening expected from a perfect sphere. A few independent investigators attempted these difficult measurements. Combining those of Franz and Saunders, with 45 points on the maria and 42 on the uplands, it was found that the maria average 5,700 feet lower than the uplands near the center of the disk, and 5,000 feet lower at the limbs. The average lunar tidal bulge is 7,200 $\pm$ 600 ft. This larger value for the bulge, would indicate that the set or freeze in the moon's figure occurred at a distance of approximately 70,000 miles about 25 million years after the moon was born. Thus, the moon solidified very early in its existence and has been of the present shape ever since.

The existence of a large fossil tidal bulge in the moon is strong evidence that the moon came into being when close to another large mass, namely the Earth, and therefore the moon was always a satellite of the Earth. Also, this rules out that the moon was captured by the Earth unless the capture occurred almost simultaneously with the birth.

The maria are ancient lava inundations, and except in the broad portions of Mare Imbrium and Oceanus Procellarum they are only a few thousand feet thick, for many crater rims extend above the lava surface (Slide 13). The maria were formed before the moon solidified to the point of rigidity. They were formed so early in lunar history that only a small fraction of the Archeozoic Era had passed. All of the Proterozoic, Paleozoic, Mesozoic and Cenozoic eras were yet to come. In spite of the antiquity of the maria, less than ten per cent of the craters are post-marian. Since there are no craters of the "walled-plain" type on the maria, it appears that their origin was peculiar to conditions prevailing only before the advent of the maria.Perhaps they were great cauldrons aiding in the dissipation of heat created by the enormous tidal friction in those times. The tidal force would have been 1/81 as severe on the Earth at this time, and because of its relation - the daily wave must have been high and very destructive. The friction in the heaving rock must have produced much heating, perhaps comparable or exceeding that derived from radioactivity.

In the United States less than one per cent of the exposed rock-strata are of Archeozoic age. How many of these layers were laid down early in era is unknown. Only in those layers could we expect to find very many large fossil craters; but these old beds have suffered intense folding, faulting, and metamorphism over the two billion years of their existence.

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With the moon we are indeed fortunate to be able to observe a planet surface that has been exposed nakedly to the awesome hazards of space for two billion years. Everything that happened on the moon since two billion B. C. would be alterations to the maria. In great contrast are the mountainous highlands that are older still, except for the minor number of subsequent happenings on them which can be gauged from the maria record. The conditions which created the mountain walled-plains ceased to exist after the maria were formed, and it is very evident that a great deal did happen before the tidal bulge was frozen. I think that the maria are the result of great tides built up rather suddenly at the time of cessation of rotation, causing the sub-terranean reservoirs of melted rock to burst out and spread over the old surface. The remains of partially destroyed craters confirm such an inundation action.

Some investigators disregard the frozen, large tidal bulge, and attempt to assign ages to the various features on terms of a constant rate of planetesimal infall. As a result, the ages of the various maria come out as several hundred million years to less than 100 million.

Dr. Konrad Buettner in 1952 pointed out that 'the lack of a filtering atmosphere lends itself to a new erosion hypothesis. Cosmic rays and solar protons, X-rays, and ultraviolet radiation hit the moon, probably not even disturbed by a lunar magnetic field'. About six primary particles arrive on the top of our atmosphere or on the moon per

square centimeter per minute. At this rate about $3 \times 10^{16}$ cosmic ray primaries per square cm have struck the moon in about a thousand million years. This is nearly one hit per crystalline bond of the surface. These primaries penetrate through 10 to 20 cm of rock, whereby a large part of their energy is used to convert nuclei, the remainder producing very strong ionization. Both effects might cause disintegration of the crystalline structure. They could be responsible for changes in color on the lunar surface. Many minerals are discolored, mainly darkened, by ionizing radiations. The bright rays radiate from the newest craters (like Tycho, Copernicus, Kepler, etc). Therefore, he considers these rays as relatively recent ejected lunar material which has not yet received the amount of ionizing radiation sufficient for darkening it. However, I find one very serious inconsistency, namely: Why haven't the older light-colored mountainous highlands turned even darker than the maria? Now, in Gold's hypothesis, the old mountainous highlands are the freshly denuded areas. (Slide 13) The debris is supposed to work its way down grade and fill up the maria with loose, darkened material. But the existence of many clefts and cleft systems on the maria and floors of flooded craters make such a creep action untenable, because all of the clefts would have been obliterated. However, the influx of high energy rays and particles on the lunar surface is something to consider.

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Tycho appears to be the last large feature produced, (Slide 14) undoubtedly caused by the impact of an asteroid. It may be less than a million years old, or it may be 50 million. Meteorites must continue to pelt the moon's surface, even at the present time.

Indeed, volcanism does not appear to be entirely extinct on the moon. A partial obscuration of the west floor of Alphonsus on October 26, 1956, was suspected by Dr. Alter when comparisons were made between the blue and the near infrared plates with details recorded on the neighboring crater, Arzachel, as a standard.

On November 3, 1958, Dr. N. A. Kozyrev happened to be taking a series of spectrograms of the central peak of Alphonsus with the 48 inch reflector at the Crimea Observatory when he noticed a bright gaseous emission with some strong Swan bands of the $C_2$ and $C_3$ molecules in spectrogram Number 2. It was exposed from $3^{h}00^{m}$ to $3^{h}30^{m}$ Universal Time. Spectrogram Number 3 was exposed from $3^{h}30^{m}$ to $3^{h}40^{m}$, in which the spectrum was normal with only a slight suspicion of the Swan bands.

On November 19, 1958, at 4 hours Universal Date and Time, Messrs. H. F. Poppendiek and W. H. Bond at San Diego, California observed a remarkable gray cloud about 20 miles in diameter over the central peak of Alphonsus. These observers watched the cloud 20 to 30 minutes and saw no change in its size or shape. This would indicate a minor eruption of gas and dust. Certainly this crater would bear much watching. How

many other similar performances have occurred unobserved elsewhere on the moon?

Several curious minute phenomena have been observed from time to time by amateur astronomers. Perhaps some of these were minor gas eruptions. Some have suspected slight condensations of carbon dioxide snow during lunar eclipses. Since there seems to be a little volcanism on the moon, it would create a slight perpetual atmosphere of escaping gases.

Around a few of the explosion craters, (Slide 15) there are signs in the immediate environs that a sudden, short-lived local atmosphere was generated. The bright ray system of Copernicus is more distorted than the other systems. The rays appear to be broken up into white splotches that suggest drifting of pulverized debris behind obstacles. The axes of these splotches several hundred miles away point toward the crater of Copernicus, as if an outward blow of wind occurred immediately following the impact. If the lunar rocks are composed of some hydrous minerals, a steam explosion may have occurred, which would dissipate with great rapidity across the airless landscape of the moon. This would blow the finely divided material, pulverized by the radial fracturing just minutes before, into the splotches seen on the photograph.

There are instances of slight colorations of green, golden, brown and even blue in very local areas, as if the ground was stained by

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volcanic vapors, or else some unusual magma constituent was segregated. An example is the brown region north of Aristarchuo.

Each month, the moon's surface goes through an intense heating by the sun, up to + 134°C. at the subsolar point, then drops to -153°C. during the long lunar night of two weeks duration. During the total eclipse of the moon on October 28, 1939, Dr. Pettit measured the temperature of the surface near the centre of the disk to be 370° Kelvin just prior to entrance into the penumbra. Within an hour, the temperature dropped rapidly to 198°K. as the moon moved deeper into the penumbra. At that time the area passed into the full shadow. During the passage through the umbra, the temperature decreased only gradually to 177°K. This is 50 degrees above the New moon temperature. This indicates conduction of some heat from below. As the moon moved out of the penumbra, the temperature rose just as rapidly and reached 370°K again at the end of the eclipse. This shows that heat flows into the body of the moon or out of it at a very slow rate, and indicates that the surface must be a very effective insulator, probably covered with dust, pulverized debris, or pumice. With such an extreme range of rapidly changing temperatures, an appreciable amount of exfoliation may have occurred. It would be most informative to compare the condition of the surface with that on the back side of the moon which is never subjected to the sudden falls in temper-

ature attending a total lunar eclipse. Such temperatures, of course, cannot have the same meaning as here, since there is no appreciable atmosphere. Drastic temperature changes would damage rocks only if there are interlocking mineral crystals with different coefficients of expansion. In order for mineral crystals to grow, the magma must be allowed to remain molten over a period of time, as accomplished by an insulating cover, which later may be eroded away on the Earth. On the moon, the surface may be more glassy because the material solidified too rapidly. Meteoritic erosion may be a more important factor.

The Russian pictures of the back side of the moon are not detailed enough to ascertain various differences, but my impression is that the broad features are not much different from the side toward the Earth.

In the spirit of a recent book so appropriately entitled by Firsoff, "Strange World of the Moon", the manned exploration of our satellite will be a most interesting and profitable adventure for science. These findings will greatly aid us in a better understanding of our own Earth, and perhaps solve the riddle of the origin and development of the solar system.

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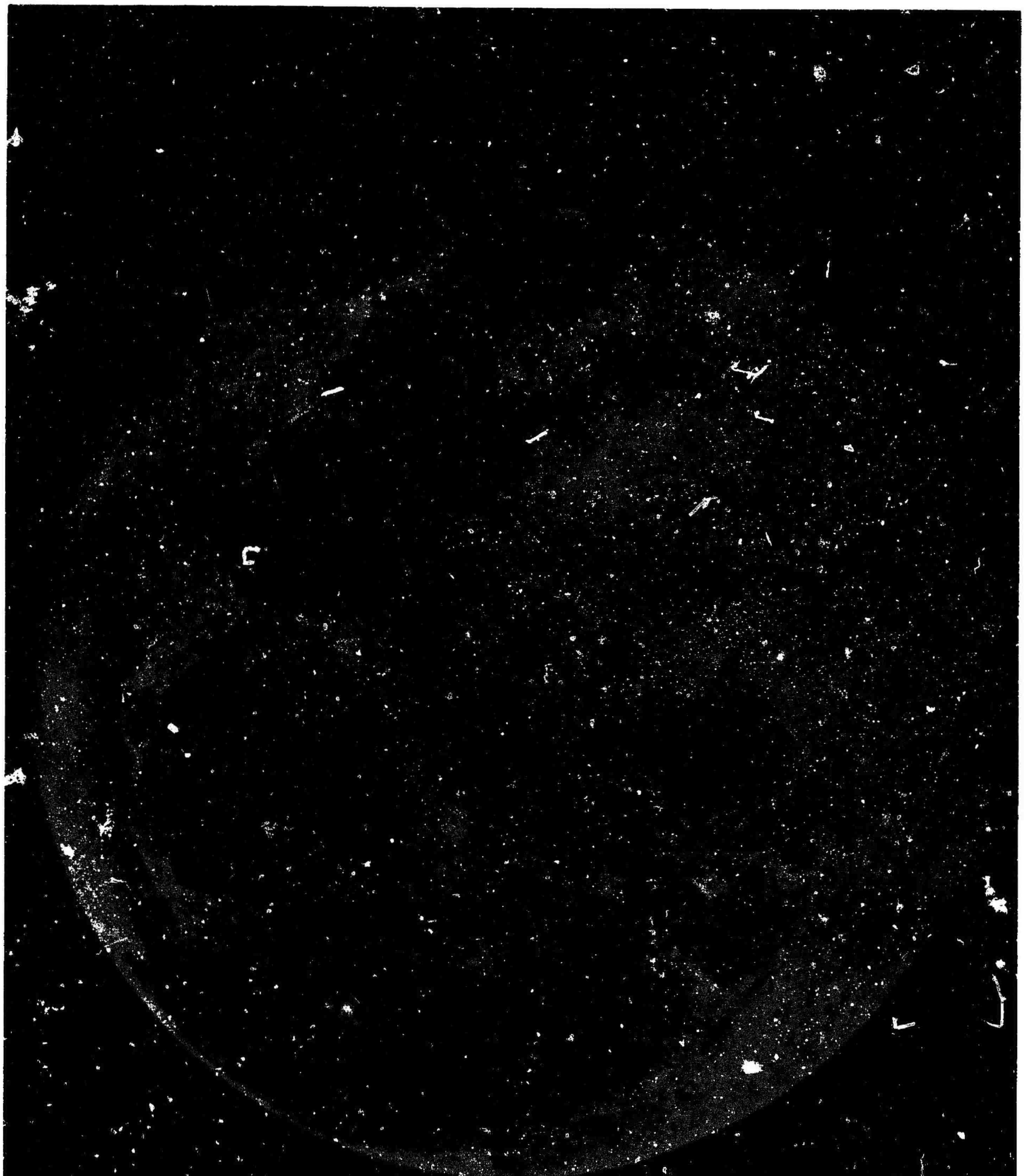

SLIDE 1

SLIDE 2

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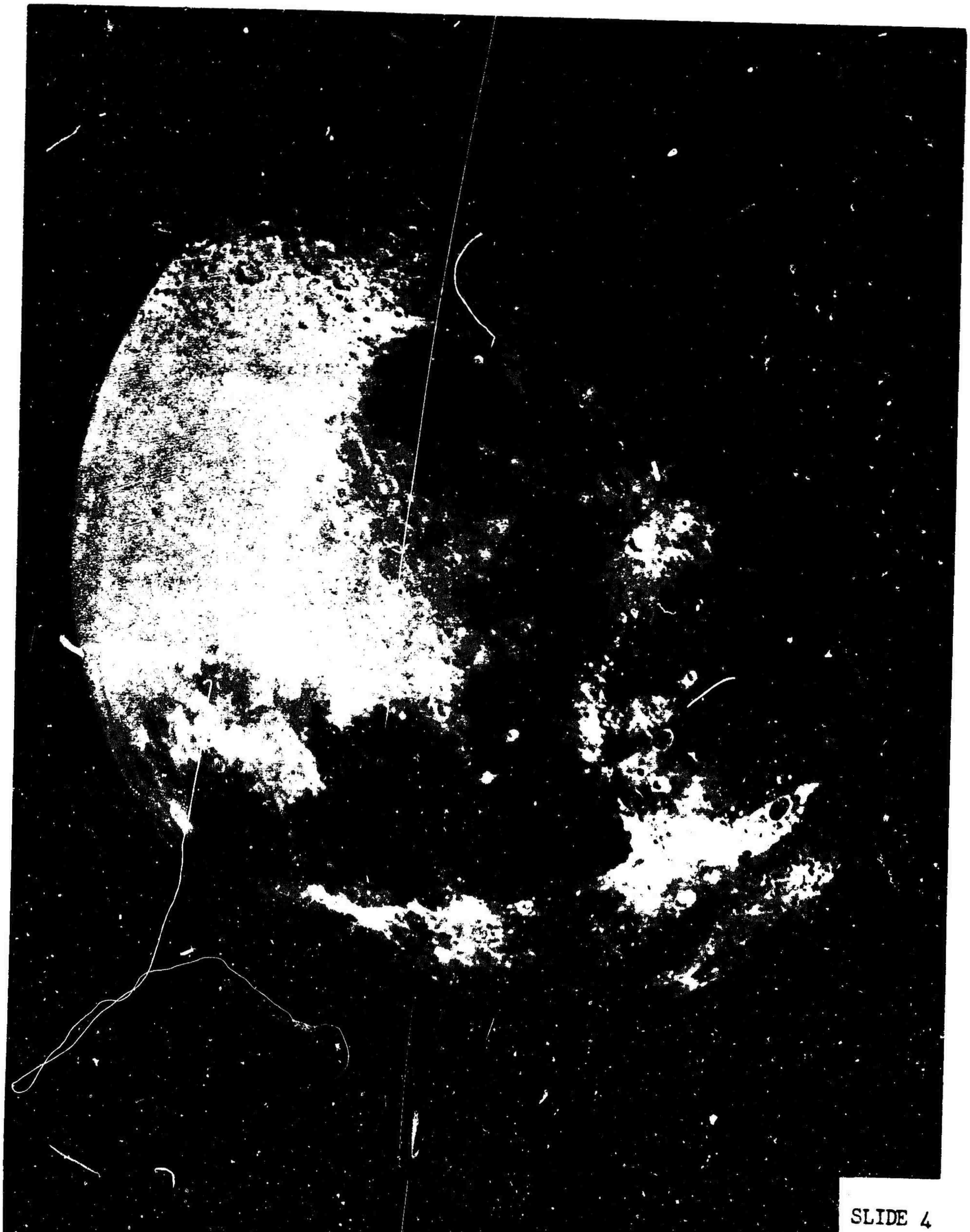
SLIDE 3



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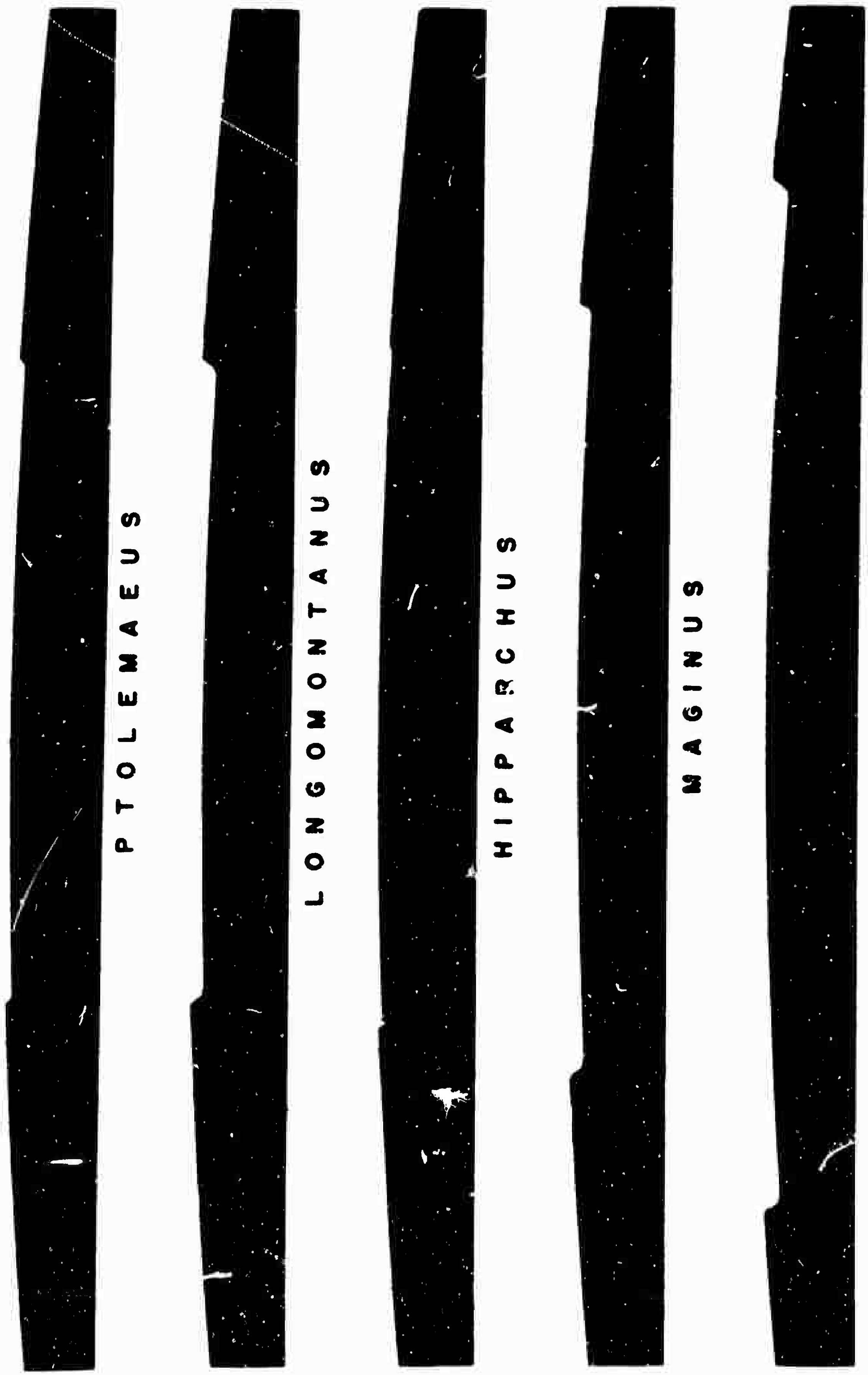
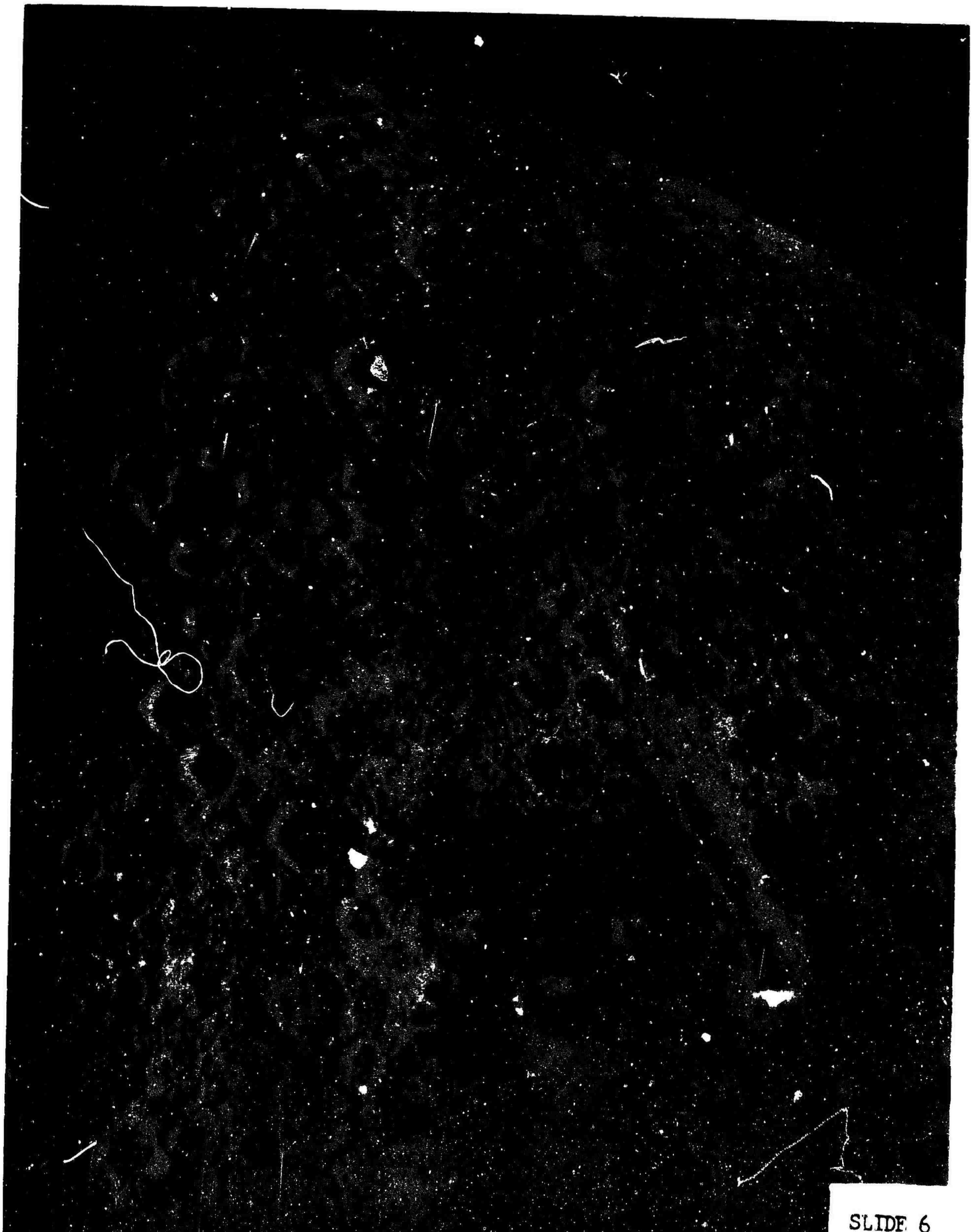



Vertical sections of some typical walled plains. SLIDE 5



SLIDE 6

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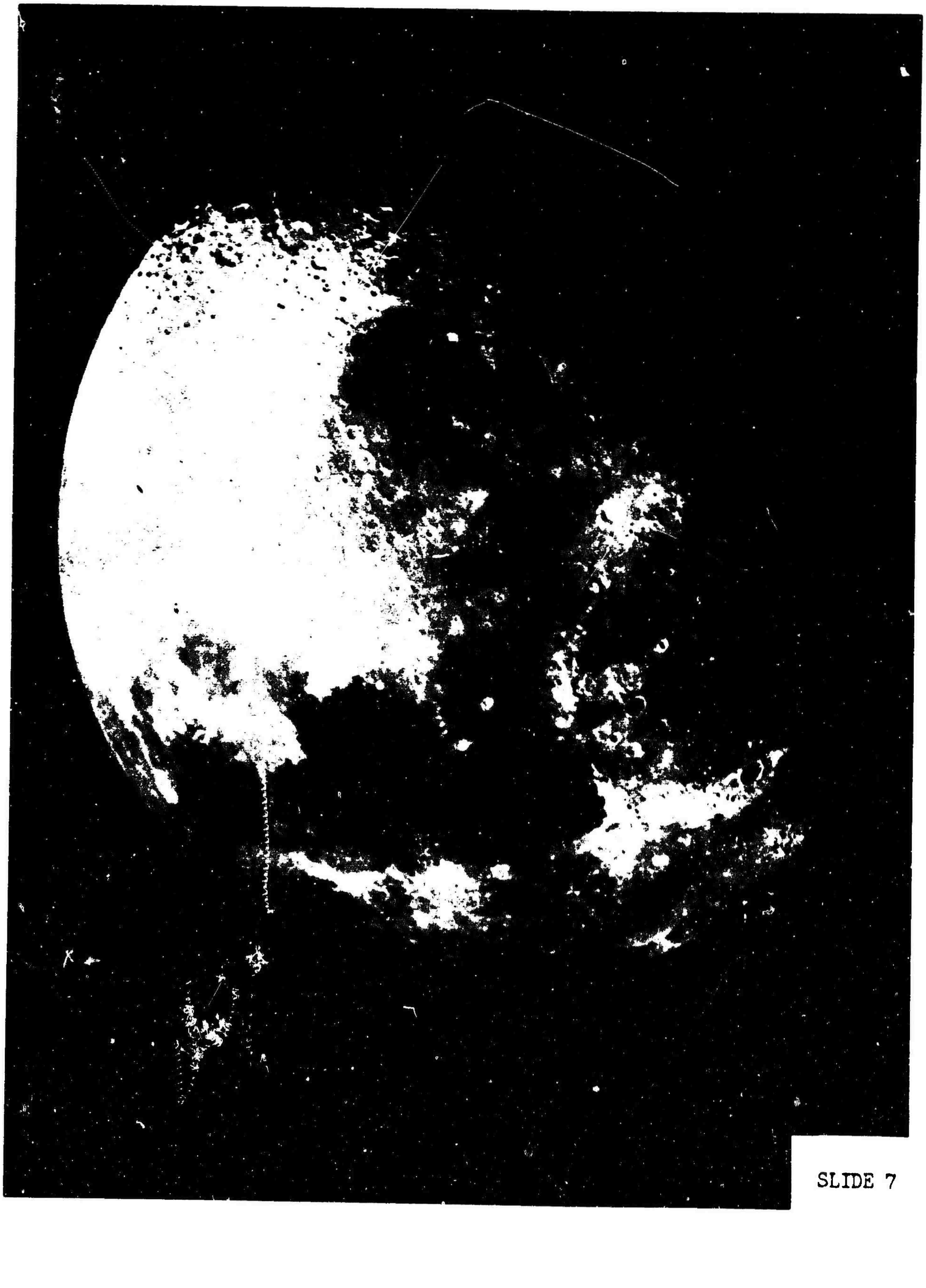

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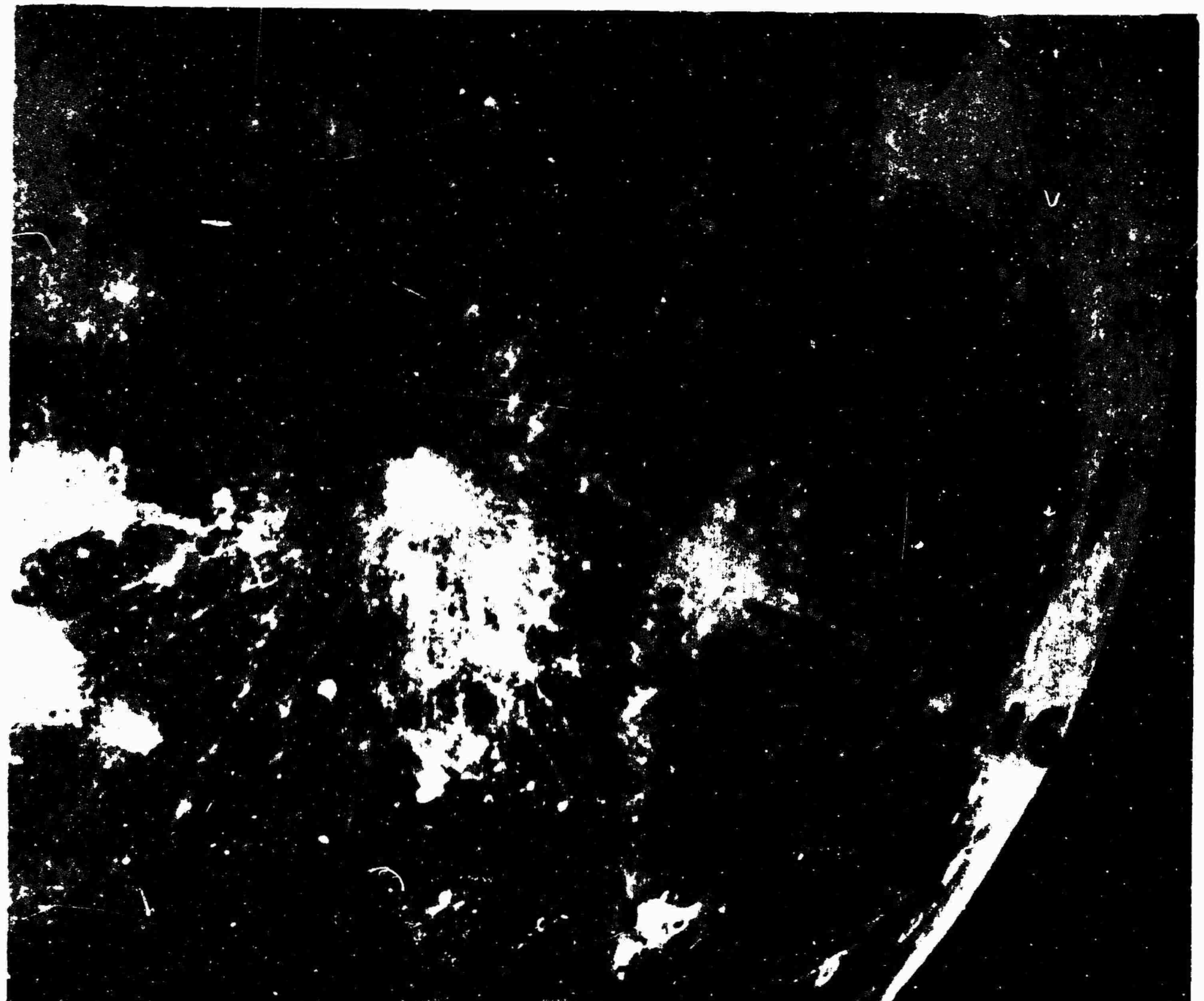
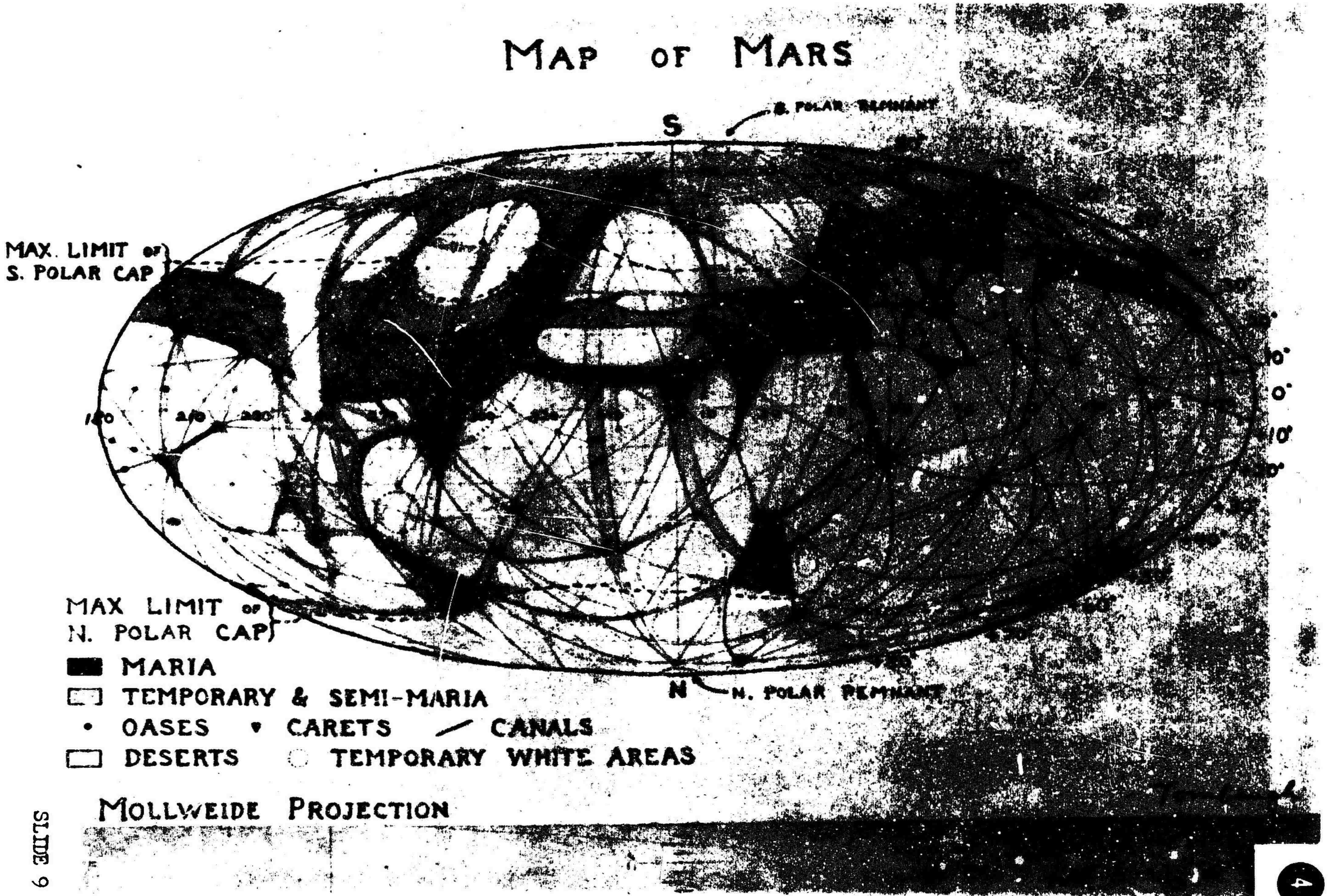


*Fig. 88.—Rays.* 40

From the craters Copernicus, left, and Kepler, right. Nearly full Moon.
(*Photograph by the Mount Wilson Observatory.*)

SLIDE 8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TEMPORARY WHITE AREAS
MOLLWEIDE PROJECTION
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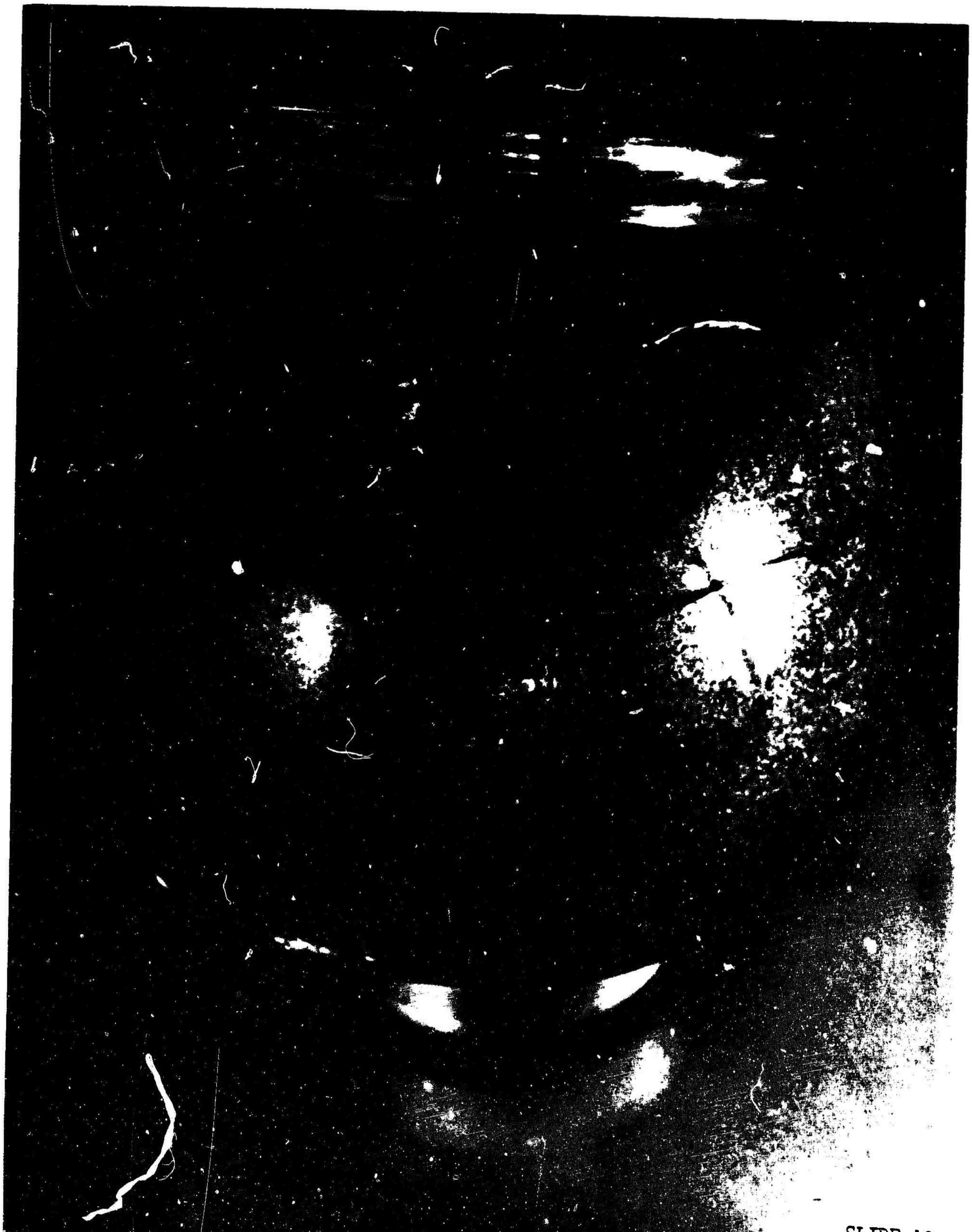
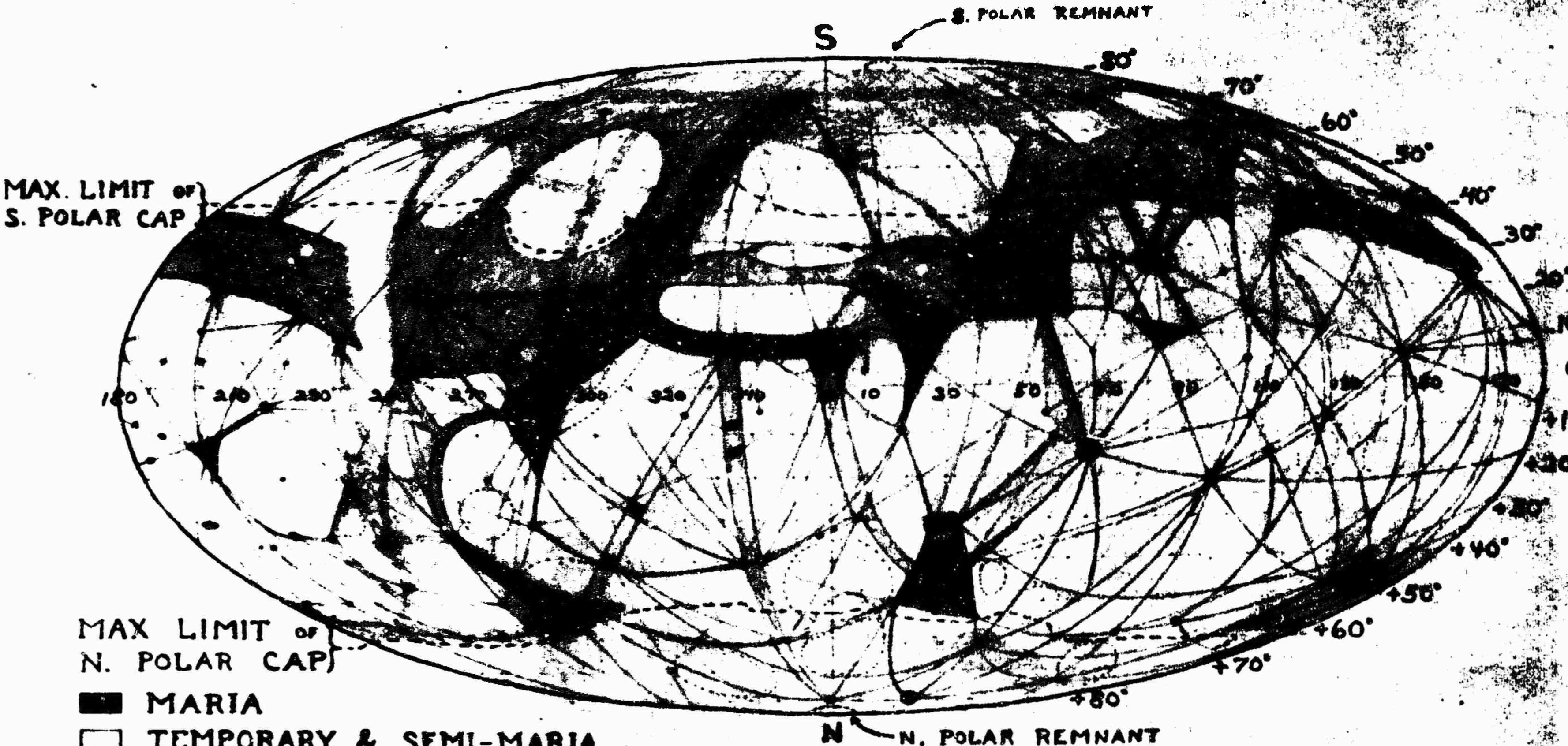
SLIDE 9



SLIDE 10

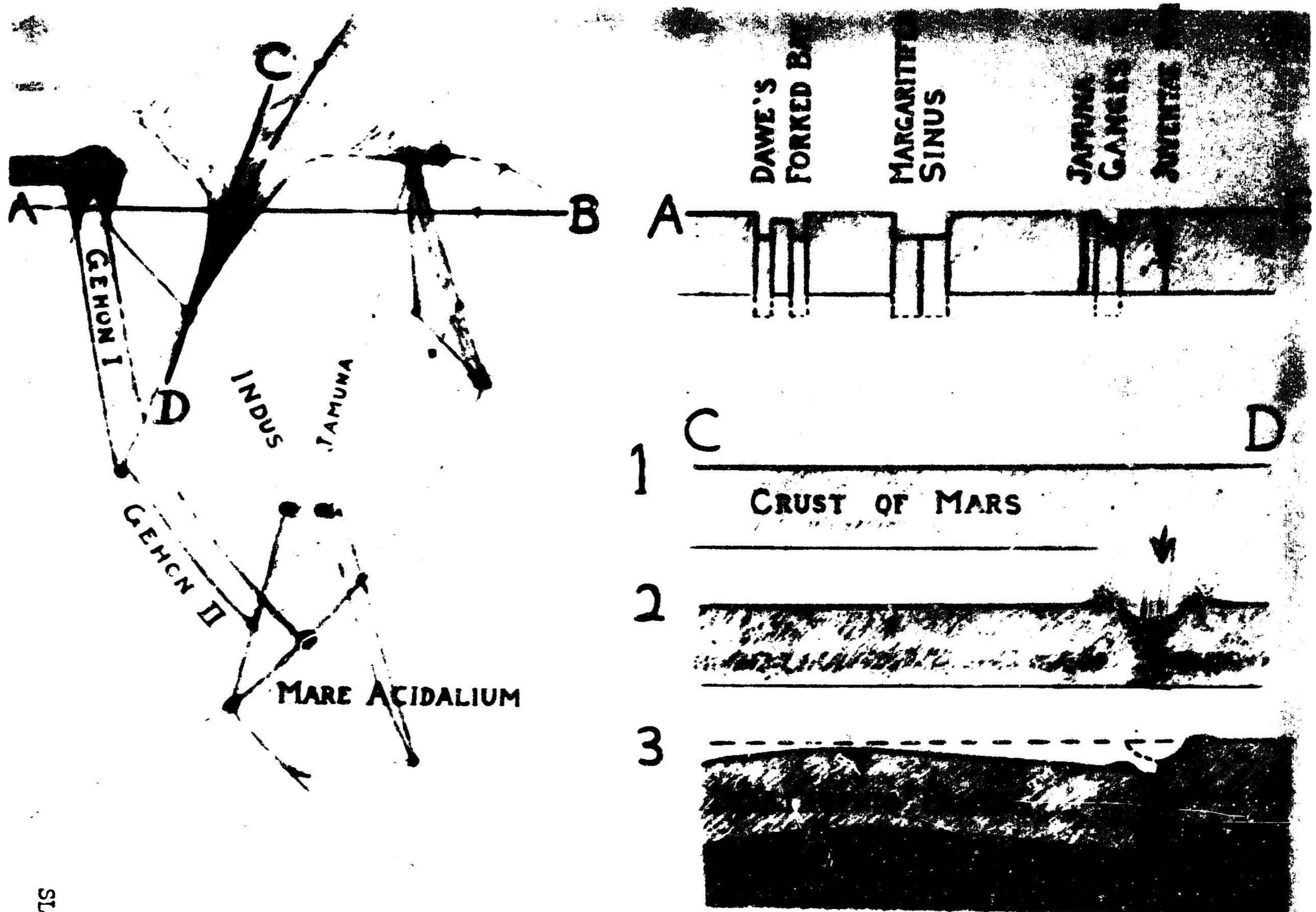
# MAP OF MARS




- MARIA
- TEMPORARY & SEMI-MARIA
- • OASES ▾ CARETS / CANALS
- DESERTS TEMPORARY WHITE AREAS

MOLLWEIDE PROJECTION

SLIDE 11




MARTIAN DIASTROPHISM & RESULTING TOPOGRAPHY

SLIDE 12

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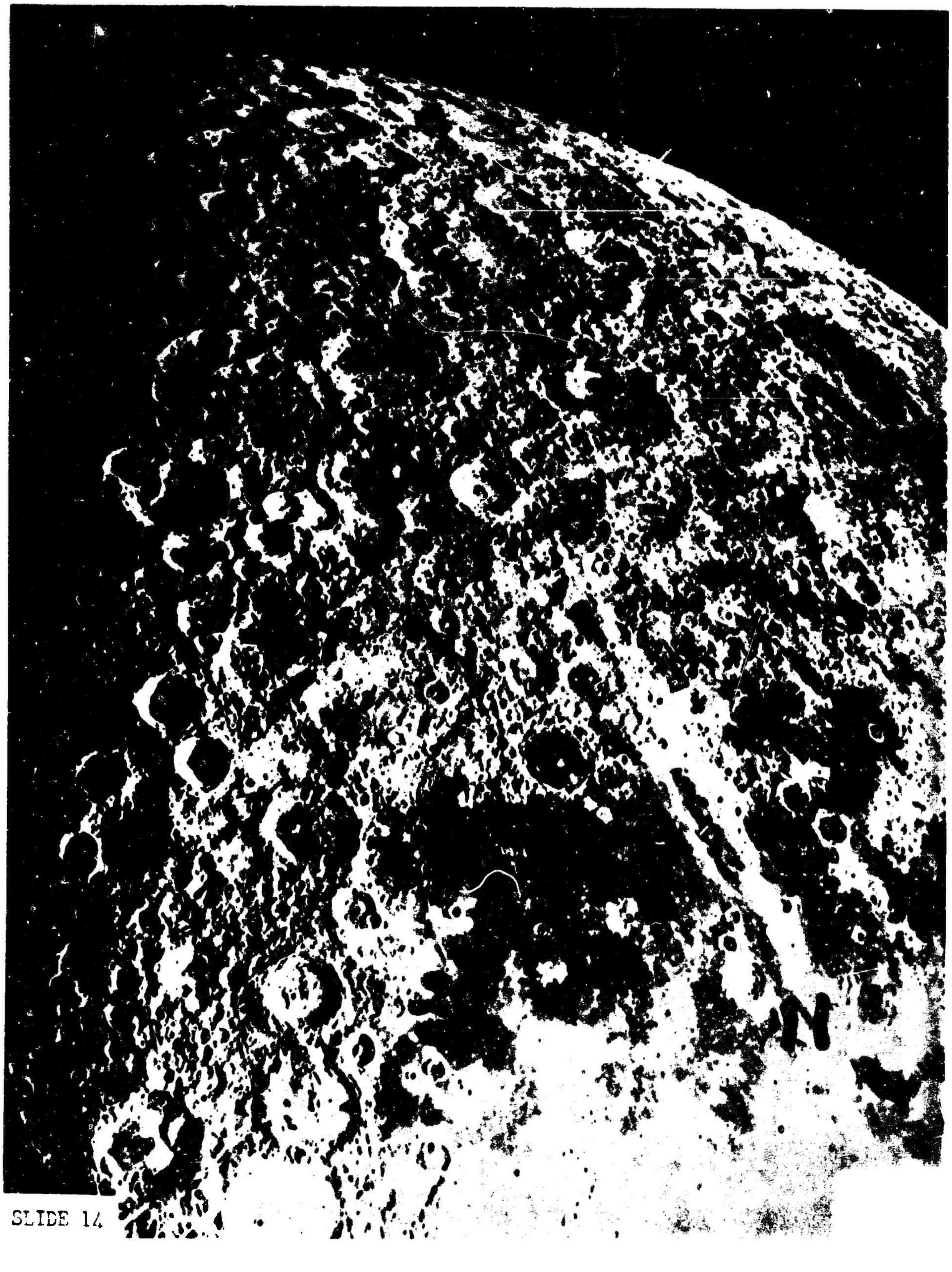
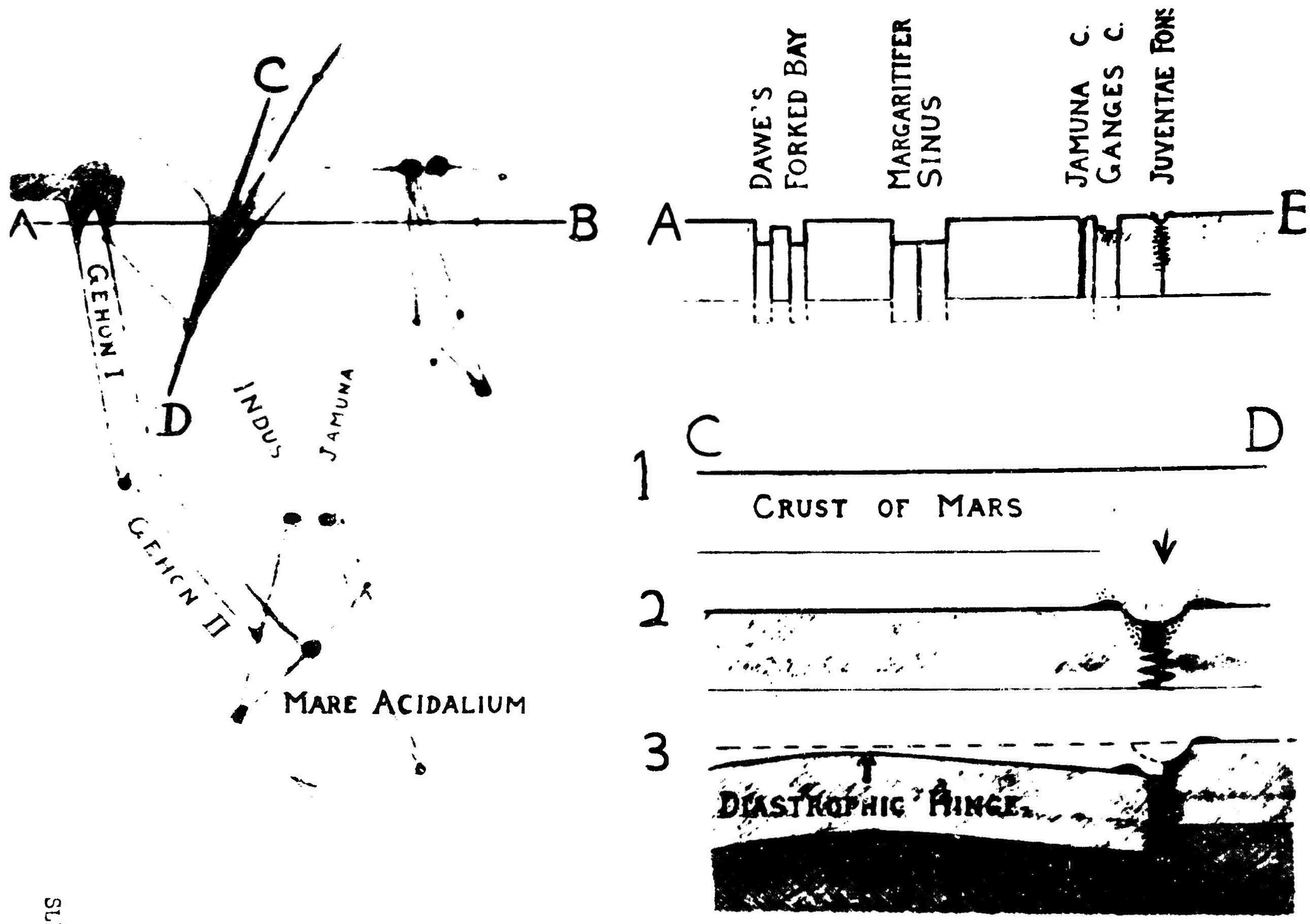
SLIDE 13




SLIDE 14




SLIDE 15

MARTIAN DIASTROPHISM & RESULTING TOPOGRAPHY

5

# LECTURES IN AEROSPACE MEDICINE

## MARS AND VENUS

Presented by

G. de Vaucouleurs

Associate Professor

Department of Astronomy

University of Texas

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MARS AND VENUS

by

G. de Vaucouleurs

Abstract

The present status of knowledge of the planets Mars and Venus was reviewed, especially the points of interest to space exploration and space medicine.

New data was presented on the structure of the upper atmosphere of venus, on the atmospheric compositions of Mars and Venus, on the probable surface temperatures of Venus, and on the variability and fine structure of the surface of Mars.

A progress report was given on the current Havard Observatory - University of Texas project for the accurate mapping of the surface of Mars.

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# LECTURES IN AEROSPACE MEDICINE

## THE UPPER ATMOSPHERE AS OBSERVED

## WITH ROCKETS AND SATELLITES

Presented By

WILLIAM W. KELLOGG
PLANETARY SCIENCES DEPARTMENT

The RAND Corporation
Santa Monica, California

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THE UPPER ATMOSPHERE AS OBSERVED WITH ROCKETS AND SATELLITES

by

WILLIAM W. KELLOGG

## Introduction

Although the word "aerospace," such a popular one these days, would seem to combine the idea of the atmosphere and space together, it is rather usual to forget about the "aero" part. Space is indeed very intriguing, and the moon and the planets seem much closer now than they used to be. But the stars in our eyes should not blind us to the very important fringe of space which we are exploring already as we move upward.

The same kind of vehicles which carry our instruments into space can also probe the upper atmosphere, and the purpose of this short review is to give a thumbnail sketch of the upper atmosphere as it has been revealed by some fifteen years of rocket and satellite probing. There are two main factors which make the exploration of this region particularly significant:

> It is the upper atmosphere that is in the most intimate contact with the outpourings from the sun, so it responds in violent and dramatic ways to changes in the activity of the sun. These are just being understood as a result of many rocket and satellite observations.

The atmosphere partly hides the sun and the universe beyond from men on the ground, so it is only by flying above the screening effect of the atmosphere that we can measure the X-ray, ultraviolet, and low-frequency radio emissions that come from the celestial bodies.

Others in this series of talks will speak of the radiations in space, and I will therefore concentrate on the upper atmosphere, its general characteristics, and how it responds to changes in solar activity.

Upper Atmosphere Under Normal Conditions

General: Figure 1 is a very general sketch, prepared some years ago but still valid for the most part, which reviews in capsule form some of the salient phenomena which takes place in the upper atmosphere and the altitudes with which they are associated. Most of these are familiar things, such as meteors, aurorae, and certain chemical reactions such as the formation of ozone ($O_3$) by the action of ultraviolet sunlight. The main features of temperature and ionization distribution will be discussed below. Note the terms for the various regions: Troposphere, stratosphere, mesosphere, and ionosphere (thermosphere).

Temperatures and winds: The atmosphere, being heated by the sun unevenly and cooled by infared radiation to space, acts as a heat engine, and is therefore constantly in motion transporting heat from the warmer regions to the colder ones. The rocket program begun before the IGY

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and continued in this country and elsewhere on a more or less regular basis has given great insight into how these complex motions behave in the upper atmosphere, above the levels of balloons, and Fig. 2 summarizes the main features in schematic form. Note the "cold low" over the winter pole in the stratosphere, and the "warm high" over the summer pole - the terms "high" and "low" refer to pressure centers, as they appear on a weather map. These features are quite persistent, particularly in mid-season, but in the transition during spring and fall the circulation is very complex indeed. (These circulations are described in detail in a forthcoming article in the Journal of Meteorology by E. S. Batten.)

The curious reversal in the mesosphere and lower ionospheres has now been definitely established as a result of the IGY series of rocket firings at Ft. Churchill, Canada, though as shown in Fig. 3 it was suspected a decade ago on indirect evidence. Perhaps the most intriguing aspect of this reversal is the question of where the heat comes from to cause the air to be hotter in winter at 80 to 100 km than in summer, even though the heating by sunlight is essentially absent in winter. One suggestion recently advanced to explain this is the possible release of chemical energy as atomic oxygen is drawn downward over the pole and caused to recombine. (A paper by this author will appear shortly in the Journal of Meteorology expanding on this idea.)

At higher altitudes the wind and temperature patterns are still poorly known. The main feature of the wind in the ionosphere is the tidal motion. In the E-region, around 100 km, it is a semi-diurnal motion, in which the tidal component is almost (but usually not quite) as great as the mean or quasi-steady component. It has a twelve-hour period because the atmosphere has a natural resonance at about twelve hours.

Higher, in the F-region and above, the tidal motion gives way to a thermally driven daily oscillation. This shows up as a reversal in wind at around midnight, and a definite change in the pressure or density as the air bulges up on the daylight side and contracts on the night side. This effect shows up quite clearly in the air densities derived from observations of air drag on satellites, as shown in Fig. 4 prepared by Hilde Kallmann, where the daytime densities are larger than the nighttime densities. (A given satellite will usually sample both sides, since the perigee, or lowest part of the orbit, is the point at which most of the air drag occurs, and the location of perigee changes in a regular way with time.)

Ionization: So much has been said about the ionosphere in its normal state that it must be a familiar subject by now. The main features of the quiet ionosphere are now moderately well understood, and Fig. 5,

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also by Hilde Kallmann, shows how well theory and observation of electron density agree. (This calculation might be revised, actually, in the light of more recent evidence on the solar UV spectrum.) Notice the emphasis on the normal, or quiet, ionosphere, where the flux of ionizing ultraviolet radiation from the sun is steady. The next section will deal with its unsteady behavior.

Effects of Solar Disturbances in the Upper Atmosphere

In the past few years the most dramatic discoveries of rocket and satellite research have centered around the phenomena which accompany storms on the sun. (The effects observed on the sun itself and its changes are being covered by other speakers, so I will only touch on them briefly.) The reasons for these advances have already been touched on: The upper atmosphere is sensitive to changes in the sun and responds in such a complex way that only by means of probes can we unravel what is happening; and the emissions from the sun that are responsible for the atmospheric effects must be observed with instruments outside the absorbing part of the atmosphere.

In Fig. 6 the solar spectrum is sketched from 1 Å (in the X-ray region) through the ultraviolet and visible and into the near infrared to 10,000 Å (1 micron). Most of the energy is clearly in the visible and near infrared, but there is still some 3 per cent between about 2000

and 3200 Å which is absorbed by ozone in the stratosphere, and there is enough energy in the far ultraviolet and X-ray regions to account for most of the ionization and heating in the ionosphere. (On this diagram a very important line due to helium emission at 304 Å is missing, its energy probably being between 5 and 15 ergs/cm$^2$ sec, though there is still some controversy over its real strength.)

The most important variations in solar emission appear to occur in the X-ray region between 1 and 100 Å, and these have been measured from rockets by Friedman and his NRL colleagues, by Hinterreger at the Air Force Geophysics Research Directorate, and others. The difficulty is in getting the rocket up just at the time of the change. The NRL solar satellite, which can monitor the sun more or less continuously, was therefore a big step forward in this respect, and NASA plans solar observation satellites to do the job even better.

The other variable in solar output is, as is now well known, the flow of charged particles (protons and electrons) ejected from active regions of the sun. These charged particles of various energies travel from the sun to the earth, where they are deflected by the earth's magnetic field and flow into the atmosphere at high latitudes, in the "auroral zone." The outer radiation belt is replenished by these solar streams. (This will presumably be discussed by J. A. Van Allen.) One very obvious manifestation of these charged particles from the sun is the

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aurora, which is the visible manifestation of their interaction with the upper atmosphere. Rockets from Ft. Churchill, in the auroral zone, have penetrated auroral arcs and have measured protons and electrons at altitudes as low as 85 or 90 km.

In order to describe some of the important changes in the upper atmosphere which accompany a solar storm, here is a brief scenario showing the kind of action that takes place. It is really more complex than this, but the main plot is revealed.

Scene I: On the sun a solar flare occurs. X-rays are emitted for a short time, and an eruption of protons and electrons takes place. If it is a particularly violent flare, some of the protons will have energies of several hundred Mev, but most are much less energetic.

Scene II: Back on the earth. X-rays, traveling with the speed of light, suddenly cause excessive ionization in the lower ionosphere (D-region), and a temporary "radio fadeout" occurs over the sunlit hemisphere. This is due to the fact that radio waves are absorbed when ionization occurs low in the atmosphere, where the collision frequency of free electrons with air molecules is large relative to the radio frequency involved. The sudden change in conductivity in the lower ionosphere also causes electrical currents to flow for a short time, and these are detected at the surface as a sudden and temporary change in the magnetic field, known as a "crochet."

Scene III: Over the polar regions. If the flare was a violent one, the high energy protons (and electrons) that were emitted reach the earth a short time (from a few minutes to a few hours) after the X-rays, and traveling down the lines of force of the earth's magnetic field they also penetrate deep into the D-region. This causes heavy ionization, and radio communication again is disrupted, but this time it is a "polar blackout" and occurs at high latitudes on both day and night sides of the earth. Brilliant auroral displays accompany a polar blackout. These energetic protons of several hundred Mev have been detected with instruments on balloons, and have also been registered in some of the NASA satellites (eg. Explorer VI and Explorer VII).

Scene IV: Over the whole earth. From a day to two days after the flare on the sun a "magnetic storm" begins. This is a complex and often violent fluctuation of the earth's magnetic field as measured at the ground, accompanied by another set of brilliant auroral displays. The cause is the arrival of the main cloud of charged particles from the sun, which is so dense that it sets up current systems in the outer part of the earth's magnetic field (the so-called "ring current"), causes hydromagnetic waves of great intensity in the ionosphere (according to a theory developed by Alex Dessler), generates electric currents in the E-region at high latitudes by enhancing the ionization there and hence the atmospheric conductivity, and again causes auroral displays. These

electric current systems are not set up exactly at the same time, so the magnetic field changes are rather complex, but a magnetic storm sequence is usually a well recognized feature on magnetic recordings over the entire world. The effects of the storm may last for as long as several days. These influxes of charged particles have been detected by instruments in both rockets and satellites, and have even been encountered in free space far from the earth by Pioneer V.

Scene V: A satellite is following its orbit about the earth. Quite suddenly, at the time of the commencement of the magnetic storm, it encounters an increase in air density at its perigee, and the rate of change of its period increases markedly. This effect has been noted by Jacchia, Priester, King-Hele, and others in satellites Sputnik III, Explorer IV, and Vanguard I (and others, no doubt, have experienced it - there is even some evidence that the Echo I satellite has been so affected). The probable explanation is that the magnetic storm heats the ionosphere, possibly through the mechanism of hydromagnetic waves generated at the outer boundaries of the earth s magnetic field, and the heated atmosphere expands and thereby causes an increase in density at each level.

So ends the drama. The story is inadequately told, and some more scenes could be added. However, the script writer is waiting for more story material from his friends who are doing the field work with rockets and satellites.

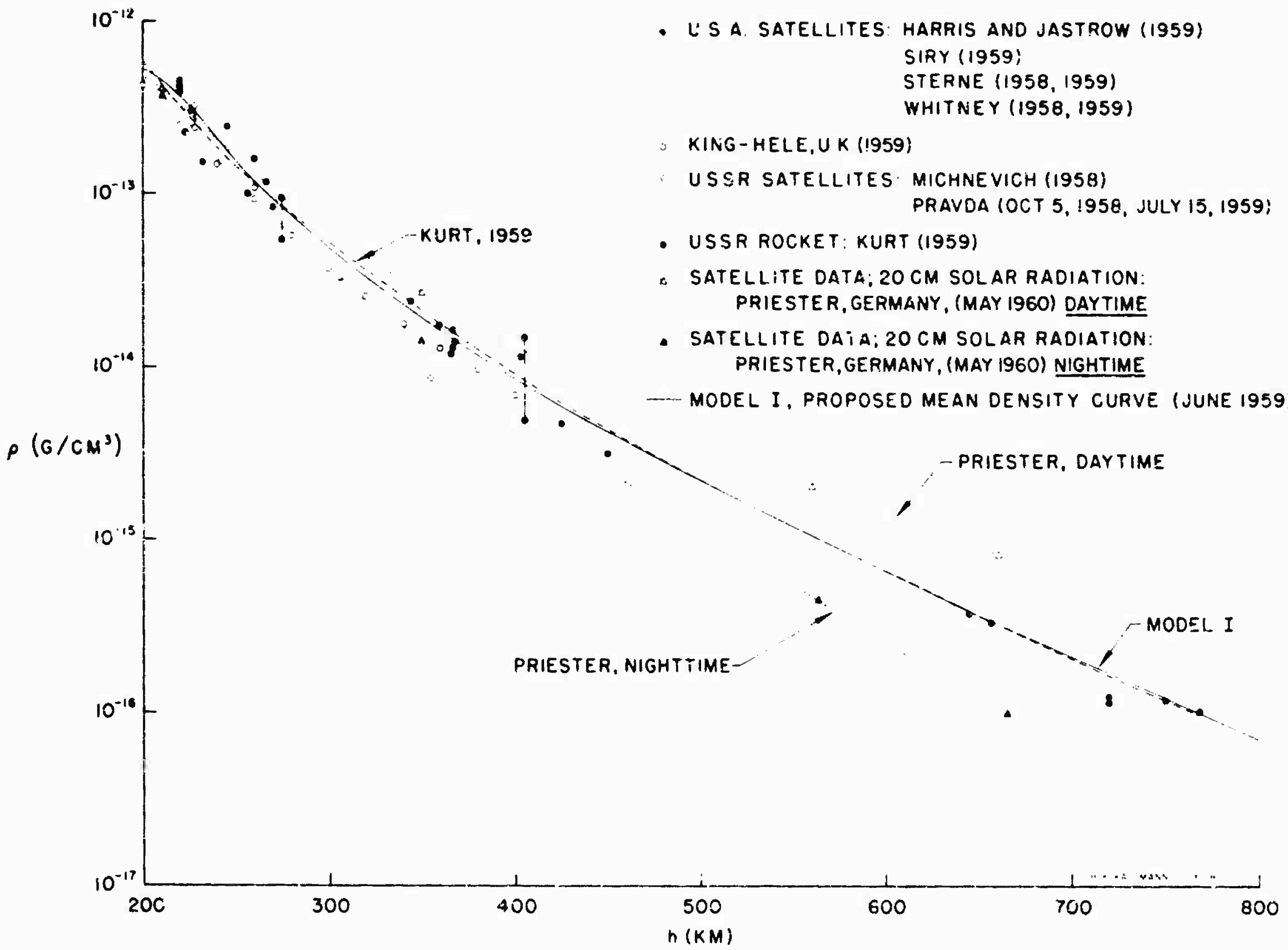


Fig. 1 - Diagram of the general structure and phenomena of the upper atmosphere. (List and Kellogg, Published in American Inst. of Physics Handbook, 1957)

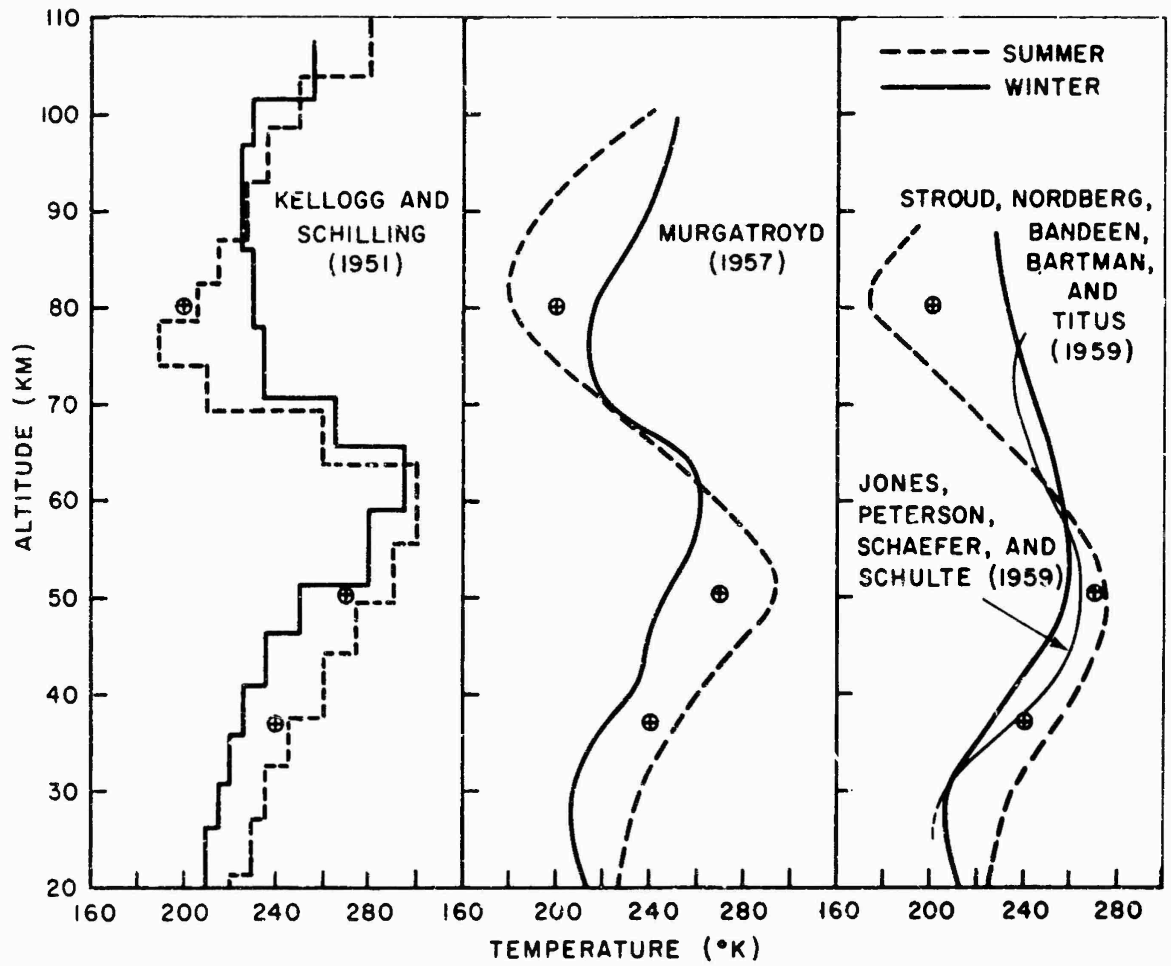


Fig. 2 - Mean winds and temperatures up to 100 km in the winter and summer hemisphere.

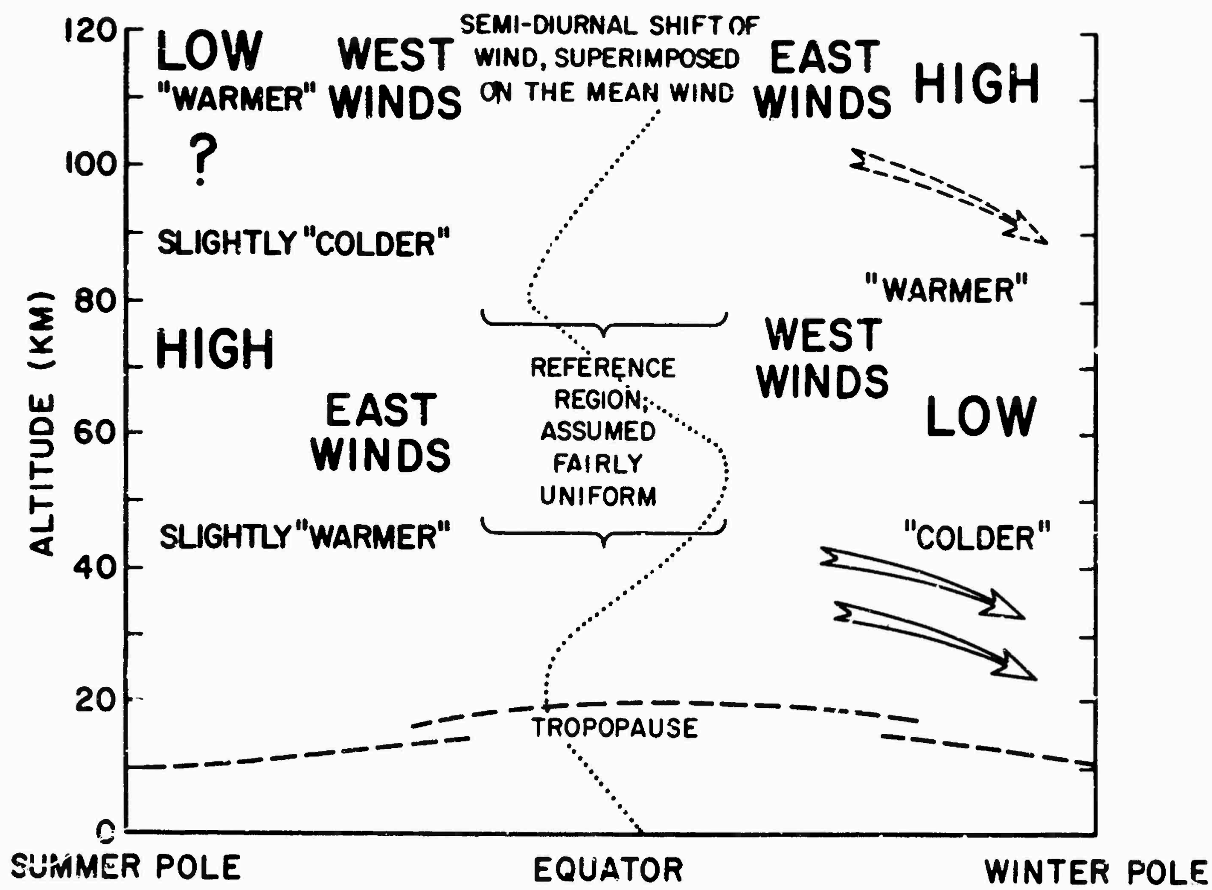


Fig. 3 - Temperatures based on theoretical calculations (Kellogg-Schilling and Murgatroyd) and observations (Stroud et al and Jones et al), at 60°N latitude for summer and winter.

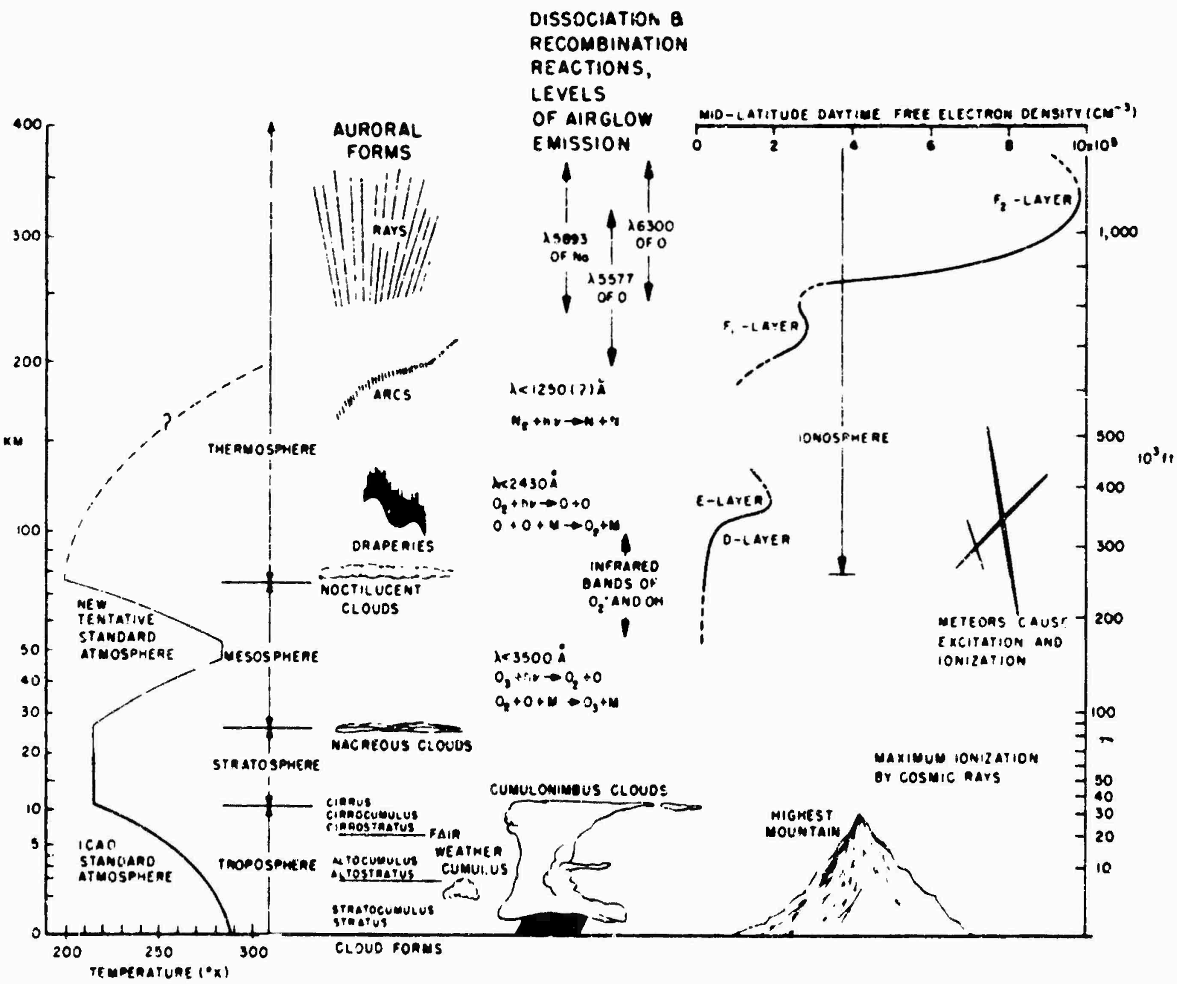


Fig. 4 - Variable densities derived from rocket and satellite observations (H. K. Kallmann).

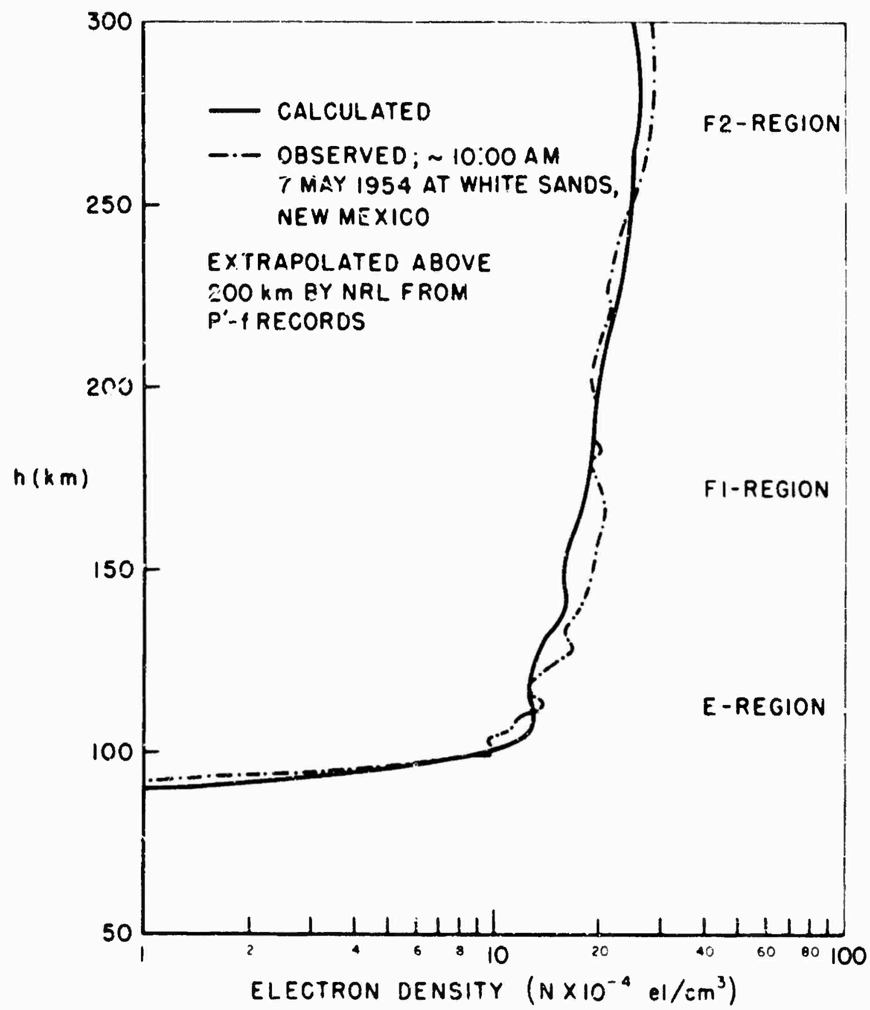


Fig. 5 - Observed and calculated free electron density distribution over White Sands (H. K. Kallmann).

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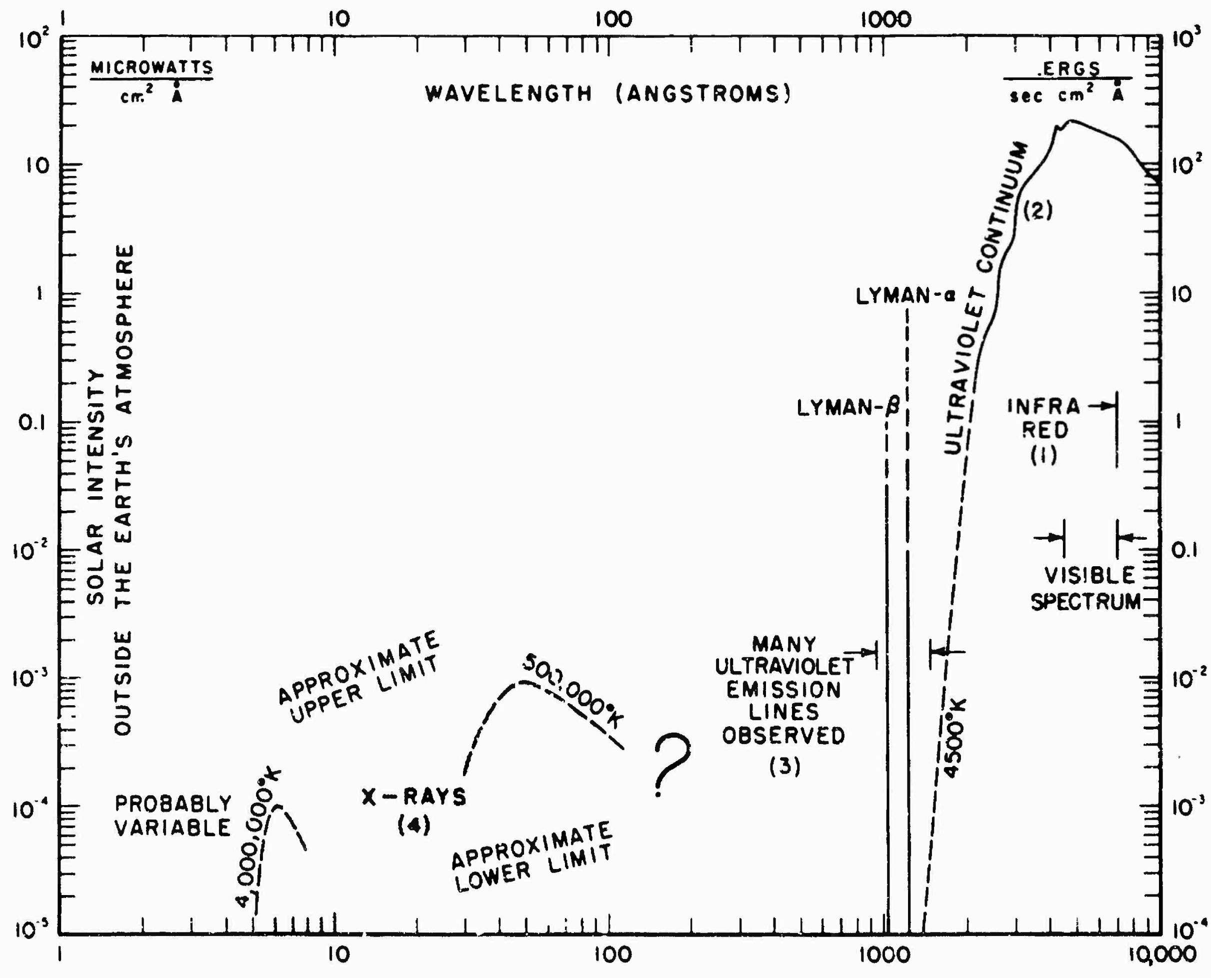


Fig. 6 - The solar spectrum from 1Å to 1 micron. (See Gazley, Kellogg, and Vestine, Jour. Aero/Space Sciences, December, 1959.

LECTURES IN AEROSPACE MEDICINE

# CORPUSCULAR RADIATIONS IN SPACE

Presented by

James A. Van Allen

Department of Physics and Astronomy

State University of Iowa

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# CORPUSCULAR RADIATIONS IN SPACE

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Iowa City, Iowa

## ABSTRACT

Present knowledge of the intensity and distribution of corpuscular radiation in the astronomical vicinity of the earth is reviewed; and an assessment, in broad outline, is given of the implications of this knowledge on the feasibility of space flight of animals and men. A "corridor of safety" from the radiation point of view lies between the earth's surface and an altitude of 400 km. within the latitude range 40°N. to 40°S. The inner zone of geomagnetically-trapped particles occupies an annular region encircling the earth and lying approximately between altitudes 600 and 7000 km. and between latitudes 40°N. to 40°S. The radiation exposure level under 1 $g/cm^2$ of iron shielding exceeds 1 r/hr throughout this region and has its maximum value of about 20 r/hr at an altitude of 4000 km. near the equator. The radiation comprises a sufficient intensity of protons of energies of the order of 100 Mev as to make effective shielding technically impractical for prolonged missions in this region (i.e., ones of more than a few hours duration). Beyond this region the earth is encircled by a second or outer radiation zone of much greater spatial dimensions, the maximum intensity of which occurs at a radial distance of about 3.6 earth radii (23,000 km) from the center of the earth. Exposure levels as high as 50 r/hr have been observed under 1 $gm/cm^2$ shields of iron. Shields of several $gm/cm^2$ of lead reduce the intensity by a factor of the order of several hundred. It is possible to make a quick escape from the earth on a space-probe trajectory with a cumulative dosage of about 10 r under 1 $gm/cm^2$ of iron. The dominant radiation hazard in interplanetary space, remote from any planet and from the sun is that due to energetic protons (and helium nuclei) which are emitted sporadically by the sun with intensities many orders of magnitude greater than the intensity of galactic cosmic radiation in the energy range greater than 30 Mev. The frequency of occurrence of such events having intensities greater than ten times cosmic ray intensity has averaged about one a month during the past two years. Typical durations are of the order of one day.

## INTRODUCTION

The known corpuscular radiations in the astronomical environment of the earth may be discussed under four headings: (1) Cosmic radiation, this term being used in the restricted sense which is traditional in this field. The more specific term galactic cosmic radiation is now being used to distinguish high-energy charged particles from non-solar sources; (2) solar protons, perhaps better termed cosmic radiation of solar origin; (3) interplanetary plasma; (4) geomagnetically trapped corpuscular radiations.

Prior to 1958, discussions of the radiation hazards in extraterrestrial flight centered on the cosmic radiation. Inasmuch as the general exposure level due to cosmic radiation is only of the order of 1 milliroentgen per hour, attention has been directed primarily toward the effects of the heavy nuclei discovered in 1948 to be present in the primary cosmic radiation by the Minnesota and Rochester groups. The heavy nuclei are, numerically speaking, a minor component of the primary beam; but owing to their production of very dense columns of ionization in material, the possibility of specific biological effects has been brought under intensive study by Schaeffer, Tobias, Curtis, Simons (1), and others. No further remarks on these matters are offered here, since the primary cosmic radiation has already been discussed by Professor Winckler (2).

The sun is a sporadic source of charged particles whose energies have been observed, on at least one occasion, (February 23, 1956), to extend up to at least 15 Bev. During the past four years a greatly expanded knowledge of solar proton events (as they are more commonly termed) has been obtained with high-altitude balloon, satellite, and space probe equipment and, less directly though more comprehensively, by ionospheric observations in the arctic and sub-arctic regions. The arrival of detectable intensities of solar protons was found to occur about once a month during the recent period of maximum solar activity. During the last half of 1959, the incidence of solar protons was much reduced. But again during April and May, 1960, the sun has been very active as an emitter of high-energy charged particles, and four recent events have been observed with notable completeness by the Iowa equipment in Explorer VII and by Minnesota and Chicago equipment in Pioneer V. The typical duration of a solar proton event is of the order of a day. The typical intensity of protons of energy greater than 30 Mev. is of the order of one hundred times cosmic-ray intensity, and

the differential number-energy spectrum follows typically an $E^{-5}$ law. There is, however, a continuous distribution of size of events, and in the few extraordinary cases observed during the past 15 years the intensity of protons of energy greater than 30 Mev may well have been several thousand times that of the galactic cosmic radiation.

Hence, on the basis of present knowledge, the sporadic emission of cosmic rays by the sun provides the dominant radiation hazard in the interplanetary flights of animals and men in regions of space remote from planets.

The interplanetary plasma, which is also attributed to the sun, apparently does not contain particles of sufficiently high energy to constitute a serious radiation hazard to the occupants of a space craft. There will be, however, significantly deleterious effects within a very thin outer layer of exposed surfaces having critical properties - e.g., photographic film, solar batteries, and plastic windows.

GEOMAGNETICALLY TRAPPED CORPUSCULAR RADIATION

The principal aim of the present paper is to discuss the current state of knowledge of the energetic particles which have been found to be trapped in the magnetic field of the earth. These trapped particles are of overwhelming biological importance for space flight in the near vicinity of the earth. Moreover, it is a reasonable presumption that corresponding radiation belts exist around all other magnetized celestial bodies of (at least) our solar system, including the sun iteslf. The recent observations of Radhakrishnan and Roberts (3) that the radio noise emission from Jupiter is strongly polarized are most plausibly interpreted as meaning that Jupiter has magnetically trapped radiation of very much greater intensity and of very much higher electron energy than that of the earth. The tentative evidence for auroral emissions from Venus suggests similar phenomena there. Hence, the earth's radiation belts may well constitute the accessible prototype of a quite general astronomical phenomenon.

By means of equipment prepared by the author and his students at the State University of Iowa and flown in U.S. satellites Explorer I and Explorer III, it was found that an immense region around the earth is occupied by a very high intensity of charged particles (protons and electrons),

temporarily trapped in the geomagnetic field. Detailed experimental and theoretical study of this radiation has become a major field of investigation during the past two years by workers in the United States and in the Soviet Union. Although knowledge of the trapped radiation is still incomplete, substantial progress has been made in observing and interpreting this newly discovered phenomenon (4).

Understanding of the dynamics of the trapping of charged particles in the geomagnetic field has also been considerably advanced by the Argus experiments of August-September, 1958. These experiments comprised the artificial injection of beta-decay electrons from the fission fragments of high-altitude detonations of small-yield atomic devices and the subsequent observation by Explorer IV, by sounding rockets, and by other techniques of the geophysical effects produced.

Figure 1 gives an over-all view of the structure of the two principal radiation zones (or belts) around the earth as derived from our Geiger-tube observations with Explorers I, III, and IV and with Pioneer III. Generally confirmatory results have been obtained by the Soviets with radiation instrumentation on Sputnik III and Lunik I. Our further observations with Pioneer IV (Fig. 2) showed the existence of massive fluctuations in the intensity structure of the outer zone (5). An immense amount of more detailed knowledge is available in the full gamut of observations with Explorer IV and with the more recent satellites Explorers VI and VII and with the deep space probe Pioneer V. Explorer VII and Pioneer V are currently active (May, 1960). In addition, valuable studies have been conducted with relatively low-altitude rockets. Many of the recent observational data are still under intensive study and have not yet been published.

## NATURE OF THE TRAPPED RADIATION

It is now established beyond all reasonable doubt that the observed radiation consists of charged particles trapped in the earth's magnetic field in the manner visualized by Poincaré, Störmer, and Alfvén in classical theoretical studies of the motion of charged particles in a static dipole

magnetic field. The nature of the particles and their detailed energy spectra are much more difficult to establish conclusively.

On the grounds of their universality in nature it is reasonable to suppose that electrons are present. Moreover, among the many nuclear possibilities, protons are likely to predominate because of the preponderance of hydrogen as an atomic constituent of matter.

The simplest working hypothesis, then, is that the trapped radiation consists of electrons and protons. If this be granted, then the problem becomes one of measuring the absolute differential energy spectrum of each of the two components as a function of position, direction, and time.

It is immediately evident from the extensive Explorer IV observations that there is no simple universal answer to the above problem. The composition of the radiation and its intensity are strong functions of position in space, of direction, and of time. A thoroughly satisfactory study of the problem is still not available.

Meanwhile, the presently available observations (obtained with relatively rudimentary equipment, by laboratory standards) have served to provide a good reconaissance of the nature of the trapped radiation. Indeed, it is the writer's opinion that the present state of knowledge is such that the full determination of the nature of the radiation, when finally available, will be interesting and valuable but probably not markedly different than that sketched below.

1. The observations with the diversity of detectors carried by Explorer IV, Sputnik III, Pioneer IV, and Lunik I demonstrate conclusively that the nature of the radiation (i.e., its composition and the energy spectra of its components) in the inner zone is quite different from that in the outer zone -- more different, that is, than the nature of the radiation in different positions within either one of the two zones considered separately.

2. The integral range spectrum of the radiation in the inner zone falls rapidly (though not precipitously)

from 1 mg/cm$^2$ to about 140 mg/cm$^2$, then trails out more gradually toward greater stopping powers. Of the radiation which penetrates 140 mg/cm$^2$, a fraction of 1% also penetrates several grams per square centimeter. On the basis of crude range and specific ionization measurements in Explorer IV, the latter, more-penetrating component is tentatively identified as consisting of protons having energies of the order of magnitude of 100 Mev. The less-penetrating radiation is quite likely electrons having energies up to about 1 Mev. and having a spectrum rising strongly (though not so rapidly as that of the auroral soft radiation) toward lower energies. Energy fluxes as high as 50 ergs/cm$^2$ sec steradian have been found beneath an absorber 1 mg/cm$^2$ in thickness.

3. The outer zone has a quite different nature. All evidence is consistent with an exclusive electron content, in so far as the characteristics of detectors used thus far permit observations -- the smallest value of absorber used being 1 mg/cm$^2$. The energy spectrum apparently resembles that of the auroral soft radiation -- rising sharply toward low energies from a practical upper limit of several hundred kilovolts. The omnidirectional flux of electrons of energy greater than 30 kev is, on occasion, as high as $10^{11}$ particles/cm$^2$ sec in the heart of the outer zone.

4. The inner zone is relatively stable as a function of time during the period of available observations, though occasional fluctuations have been observed.

5. There are marked temporal fluctuations in the "slot" between the two zones, and fluctuations of very great magnitude in both intensity and spatial structure in the outer zone. These fluctuations are apparently associated with solar activity.

## RADIATION EXPOSURE LEVELS

With equipment shielded in about the manner that ordinary, minimum structural considerations for space vehicles would dictate ($\sim$1 g/cm$^2$ of intermediate-Z material), exposure levels of some 20 r/hr have been observed in the heart of the inner zone; and exposures of several times this level, in the heart of the outer zone.

The radiation level in the inner zone is only mildly reduced by 4 $g/cm^2$ of lead. But the radiation level in the outer zone is reduced by a factor of at least 500 by the same lead shield (Pioneer IV).

Of course, the exposure levels on the exposed skin of a space vehicle are many times as great, especially in the outer zone.

## ORIGIN OF THE TRAPPED RADIATION

In view of the extensive body of knowledge concerning "solar-terrestrial" relationships, and our earlier discovery of the auroral soft radiation, it was originally suggested that the trapped corpuscular radiation consisted of ionized solar gas which had been injected into the geomagnetic field, with perhaps acceleration to the observed energies being a local phenomenon in the geomagnetic field.

Subsequently, various workers have proposed that the trapped radiation may arise, at least in part, from other processes. Christofilos, Vernov, Kellogg, and Singer (see ref. 4) have drawn attention to the neutron component of the cosmic-ray albedo as a possible source, and the last-named author has emphasized the potentiality of such high-energy neutrons for generating the penetrating component in the inner zone. These suggestions depend on the ability of neutrons from cosmic-ray-induced nuclear disintegrations in the atmosphere to move outward through the geomagnetic field without deflection until they undergo radioactive decay. The decay products of a neutron (half-life at rest, 11.7 minutes) are an electron, a proton, and a neutrino. The kinetic energy of the proton is comparable to that of its parent neutron, the electron has a well-known beta-decay spectrum (upper limit 782 kev for a neutron at rest), and the neutrino does not contribute to the observed geophysical phenomena.

The observed spectrum and composition of the radiation in the inner zone appear consistent with the neutron-decay hypothesis of origin, the major component being electrons having an energy spectrum resembling that of neutron decay electrons and the minor(but penetrating) component being protons of energy of the order of 100 Mev. Many quantitative considerations remain to be examined before the neutron-decay origin of the inner zone can be

regarded as established, but the present state of knowledge favors it. The rocket work of Freden and White (6) and of Yagoda (7) has provided the best available data on the spectrum of the proton component in the lower edge of the inner zone.

There is little doubt that the great outer zone and the immense variety of associated geophysical effects are attributable to solar gas, injected into trapped orbits in the geomagnetic field. It is probable that the particles in the outer zone are accelerated to their observed energies by means of time and space fluctuations of magnetic intensity in the outer fringes of the geomagnetic field.

## LOSS OF TRAPPED PARTICLES

The trapped particles slowly lose energy by collisions with molecules of the atmosphere; in addition, they diffuse downward along magnetic lines of force, owing to scattering. This quiescent "leakage" is probably the major element in the loss of trapped particles from the inner zone, wherein the magnetic field is strong and only mildly fluctuating. A lifetime of the order of 10 years is required in order that the decay products of neutron albedo maintain the observed intensity.

The quiescent leakage occurs in the outer zone also, but here it is likely that the dominant loss process is one of a much more chaotic and precipitous nature and has its origin in fluctuations of the magnetic field. Loss may be by "dumping" into the atmosphere or by release into interplanetary space. Marked fluctuations in the outer zone occur from hour to hour and even from minute to minute during disturbed conditions, though occasionally the outer zone is relatively stable over periods of several days.

## COMPOSITION OF THE TRAPPED RADIATION

The tabulated material below gives a tentative summary of the composition of the trapped radiation in the heart of the inner and the outer zones. The figures for the outer zone are for March 3, 1959, a day of especially high intensity. The more usual situation in the heart of the outer zone is characterized by intensities lower by one or two orders of magnitude.

Heart of Inner Zone (Usual Situation)

(a) Electrons, E $> 30$ kev -- $\sim 2 \times 10^9/cm^2$ sec steradian
(b) Electrons, E $> 600$ kev -- $\sim 1 \times 10^7/cm^2$ sec steradian
(c) Protons, E $> 40$ Mev -- $\sim 2 \times 10^4/cm^2$ sec

Heart of Outer Zone (A situation of especially high intensity)

(a) Electrons, E $> 30$ kev -- $\sim 1 \times 10^{11}/cm^2$ sec
(b) Electrons, E $> 200$ kev -- $\leq 1 \times 10^8/cm^2$ sec
(c) Protons, E $> 60$ Mev -- $\leq 10^2/cm^2$ sec
(d) Protons, E $< 30$ Mev -- No significant information

PRACTICAL SPACE FLIGHT CONSIDERATIONS

1. Within the approximate geographic latitude range 40°N to 40°S and for all longitudes the trapped radiation appears to be of negligible intensity below an altitude of about 400 km (Fig. 3). Hence the radiation hazard in prolonged flights of man and animals within this region is simply that due to the ordinary cosmic radiation. It is of interest to remark that the relative absence of trapped radiation below 400 km (8) is due to the relatively high atmospheric density there (i.e., compared to that at, say, 2000 km). The increasing atmospheric density at lower altitudes does, of course, limit the flight lifetime of satellites because of air drag. However, flight lifetimes of several years are possible if the altitude of perigee is greater than approximately 250 km. The combination of the two criteria just mentioned leads to the suggestion that nearby space stations which are to be operated and inhabited for periods of several years should have a perigee altitude greater than 250 km and an apogee altitude less than 400 km. It appears prudent to use orbital inclinations not greater than 40° to the earth's equatorial plane. Orbits of higher inclination are subject to the considerably enhanced leakage (or precipitation) of trapped radiation down to low altitudes in the auroral zones. Usually the auroral radiation is easily shielded (1 mm of lead), but there are sporadic bursts of more penetrating radiation of substantial intensity. Overall, the biological risk is probably not great; but present evidence suggests that this risk should not be accepted unless there

are compelling reasons for orbits of high inclination. Meanwhile, it is of importance to extend radiation observations to high latitudes with both low- and high-altitude satellites.

2. The exposure level in the heart of the inner zone is about 20 r/hr within a shield of 1 $g/cm^2$ of iron. Owing to the great penetrability of the high-energy protons therein, effective shielding is quite beyond engineering feasibility in the near future. Hence, the inner zone must be classed as an uninhabitable region of space.

3. A nearly circular satellite orbit having a period of 24 hours has a radius of about 6.6 earth radii. As shown by Pioneer IV observations, such an orbit may be expected to be engulfed, from time to time, by very intense radiation, giving exposures of the order of tens of roentgens per hour within a shield of 1 $g/cm^2$ of intermediate-Z material, and, of course, enormously greater exposures on the outer skin. The energetic portion of the radiation appears to consist mainly of electrons having energies less than 100 kev. The electrons themselves can be quite easily absorbed in a low-Z material, and the resulting bremsstrahlung can be substantially reduced in intensity by several millimeters of lead (several grams per square centimeter).

Perhaps the more usual geophysical situation is represented not by that encountered by Pioneer IV (March 3, 1959) subsequent to an intense solar outburst in latter February, 1959, but by that encountered by Pioneer I on October 11, 1958, by Pioneer III on December 6 and 7, 1958, and by Lunik I on January 2, 1959. In these cases, the intensity at 6.6 earth radii was down from its peak value (at about 3.5 earth radii) by a factor of over 500. Nonetheless, very great fluctuations may be expected in the outer reaches of the earth's magnetic field.

Protons, though probably present in the outer zone with large intensities, appear to have such low energies that they are unobservable under a shield of 1 $g/cm^2$. Nonetheless, they may produce significant radiation damage to the superficial skin of a space craft.

4. The "slot" between the inner and outer radiation zones is a region in which the radiation intensity has a relative minimum value. The slot crosses the equator at a radial distance of about 2.4 earth radii from the center

of the earth. The radiation exposure level there is approximately 1 r/hr inside a shield of 1 g/cm$^2$. The radiation in the slot is attenuated by about a factor of 10 by 4 g/cm$^2$ of lead and is therefore probably a mixture of the penetrating radiation which characterizes the inner zone and of the much softer radiation in the outer zone. The present writer judges that the "slot" is not a particularly favorable site for prolonged flight of manned vehicles, though its existence may be advantageous for short-term missions.

5. Present evidence suggests that satellite orbits having their perigees at more than 15 earth radii from the center of the earth are subject to a negligible intensity of trapped radiation, though there is speculation that the bursts of solar plasma which pass outward through the solar system may contain sufficiently energetic particles to constitute a significant, though perhaps short-term, radiation hazard. The interplanetary observations with Pioneer III, Pioneer IV, Lunik I, and Pioneer V are contrary to this line of speculation but do, of course, constitute a meager temporal coverage of the matter. At present, it appears more probable that the trapped particles gain most of their observed energy in accelerative processes associated with the geomagnetic field. But the question is still moot and will be settled only by prolonged radiation measurements in interplanetary space, remote from the earth.

6. Consideration will now be given to space missions involving prompt escape from the earth. With Pioneer IV as an example, the trapping region can be completely traversed in about 6 hours with some 2 hours being spent in the high-intensity region. Hence the cumulative dosage on a trajectory of this nature would be of the order of 10 r in a lightly shielded craft (1 g/cm$^2$) and could be further reduced by a low-Z material for the superficial skin of the craft (e.g., beryllium, in which the efficiency for production of bremsstrahlung is less).

In any case it appears wise to evade the inner zone, and this is not difficult to do, since its latitudinal and radial extent is limited.

The outer zone is much more difficult to avoid. There do appear to be "cones of escape" over the north and south geomagnetic poles. The half-angle of these outward-opening cones is about 20°. The detailed nature of these cones has not yet been examined by direct observations. On the basis of the radial investigations of the intensity of trapped radiation and on the basis of the basic, elementary theory of geomagnetic trapping (which is now well established as describing the major features of all observations to date), it appears that there is little likelihood of trapped radiation of significant intensity within the cones specified above. Nonetheless, this inference should be checked by satellite observations in pole-to-pole orbits. Also it may be possible for solar plasma, on occasion, to enter the polar regions directly and not via the trapping region. And on such rare occasions as that of February 23, 1956, there may be enormous, though transient, influxes of cosmic radiation of solar origin.

7. The Argus experiments have demonstrated that a quite high radiation intensity of trapped, high-energy electrons can be produced artificially in selected regions of space for short periods of time. The full implications of this demonstration are quite considerable. The detailed results should be studied with care by all those who have responsible concern for future space flight.

RADIATION DAMAGE TO ELECTRONIC AND OTHER EQUIPMENT

The radiation tolerance of electronic and other physical equipment is in general vastly greater than that of animals. Typically, cumulative dosages of the order of millions of roentgens are required to produce important effects, though the characteristics of semiconductors in critical circuits may be appreciably affected by smaller dosages. It is believed that the earlier discussion and reference to original papers provide a basis for engineering assessment in any specific case.

The successful operation of the solar batteries and the transmitter of Vanguard I (Satellite 1958 Beta) for over two years (as of present date of writing) and the successful operation of similar equipment in Sputnik III

(Satellite 1958 Delta) over a similar period provide the most direct evidence for the survival of electronic equipment in space vehicles. The integrated radiation exposures in these two cases are still much below the level at which serious deterioration may be expected.

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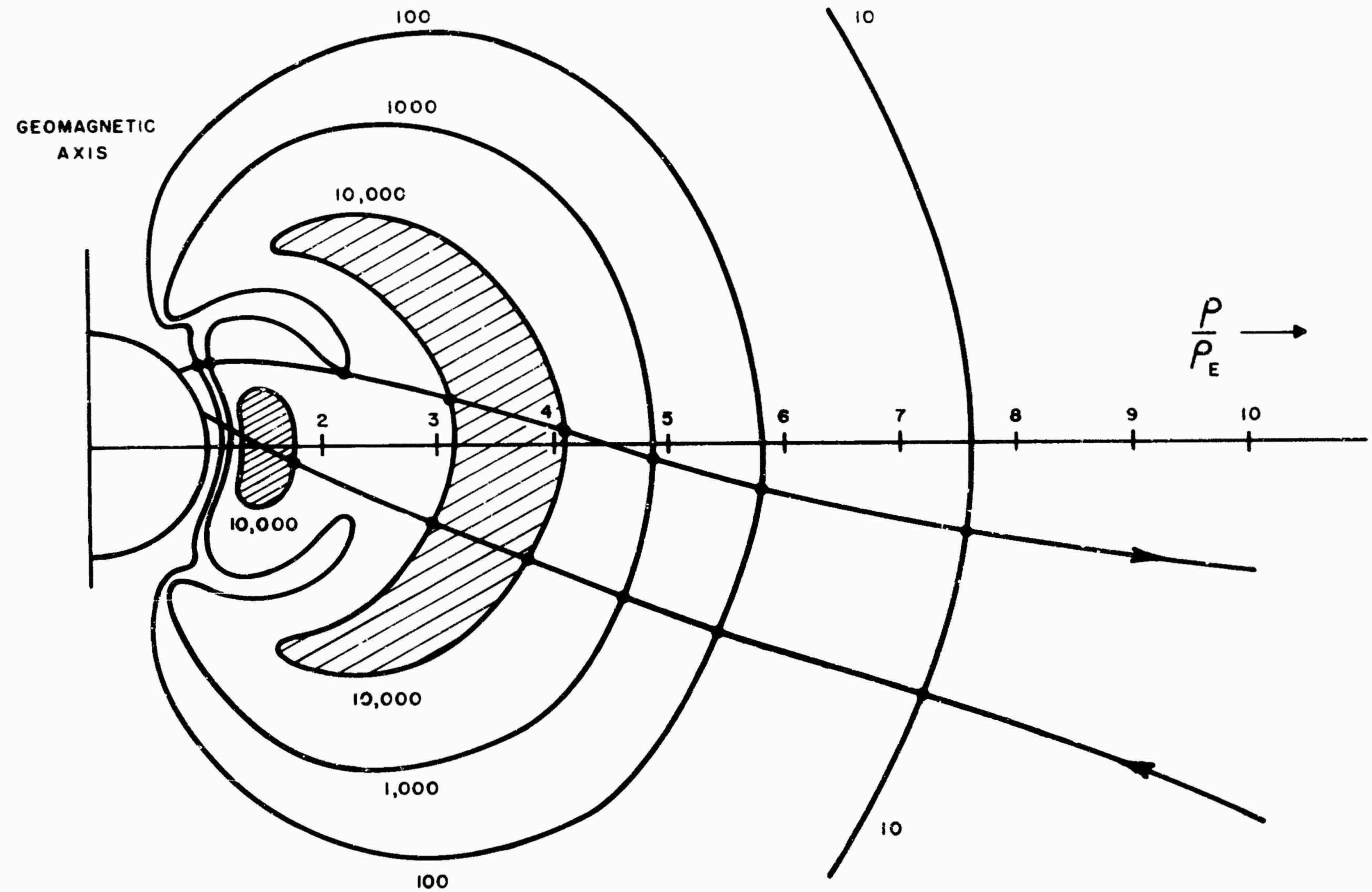
## FIGURE CAPTIONS

Fig. 1 Intensity structure of the trapped radiation around the earth. The diagram is a section in a geomagnetic meridian plane of a three-dimensional figure of revolution around the geomagnetic axis. Contours of constant intensity are labeled with numbers 10, 100, 1000, and 10,000. These numbers are the true counting rates of an Anton Type 302 Geiger tube carried by Explorer IV and Pioneer III. The linear scale of the diagram is relative to the radius of the earth -- 6371 km. The outbound and inbound legs of the trajectory of Pioneer III are shown by the slanting, undulating lines.

Fig. 2 A comparative plot of the radiation intensities as measured with nearly identical Anton 302 Geiger tubes in Pioneer III and Pioneer IV. The trajectories were not identical, the most important difference being that Pioneer IV cut through the inner zone several degrees closer to the equator, at a radial distance of about 10,000 km.

Fig. 3 True counting rate of the Geiger tube in Explorer I as a function of altitude above sea level for a number of longitudes all near the magnetic equator. Note the precipitous rise in intensity at an altitude ranging from 400 km over the central Atlantic (curve on left) to 1300 km over Singapore (curve on right). See ref. 8 for details.



GEOMAGNETIC AXIS
100
1000
10,000
10,000
10,000
1,000
100
10
10
2
3
4
5
6
7
8
9
10
$\frac{\rho}{\rho_E}$


Figure 1

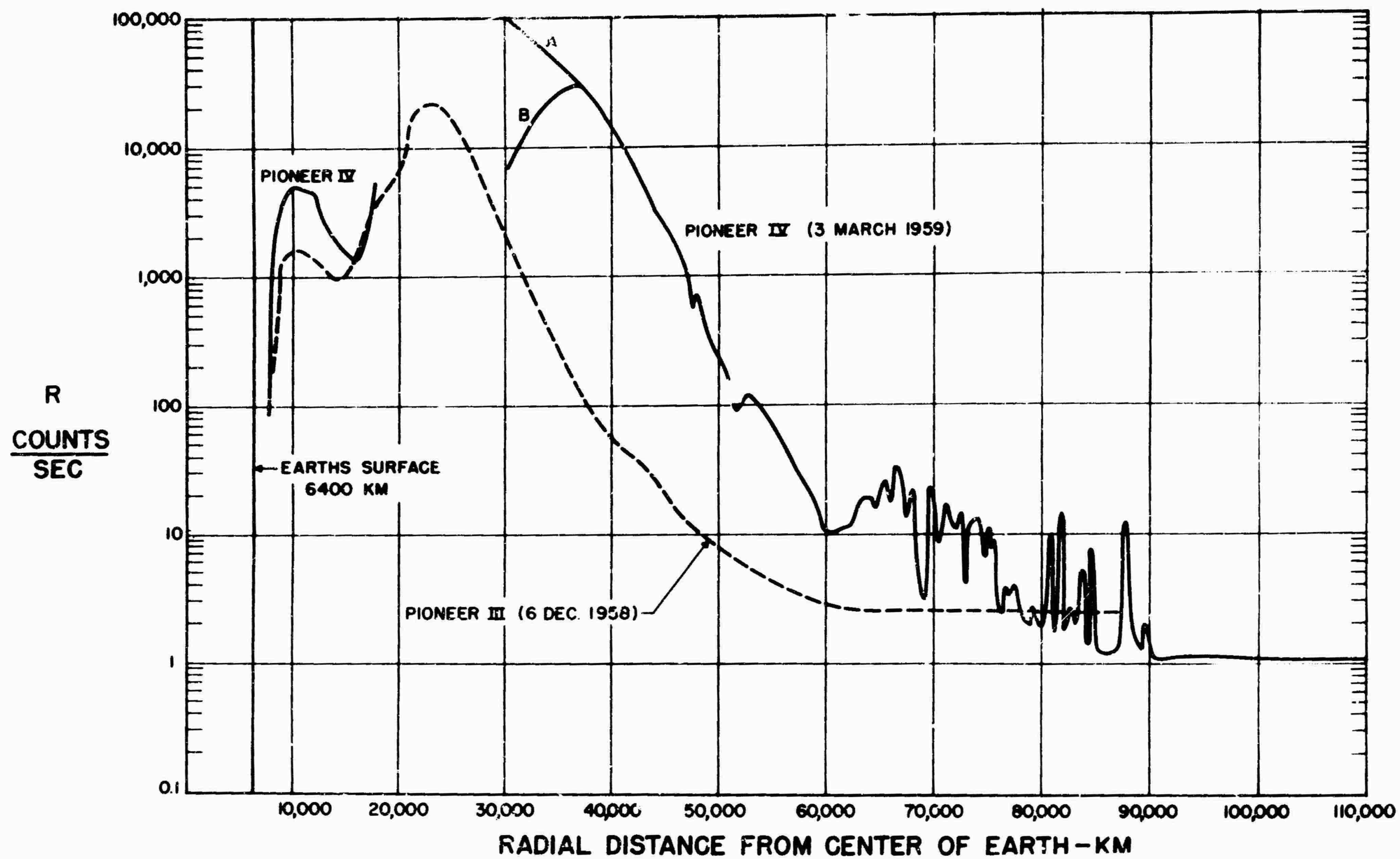

R
COUNTS
SEC
100,000
10,000
1,000
100
10
1
0.1
PIONEER IV
PIONEER IV (3 MARCH 1959)
A
B
EARTHS SURFACE
6400 KM
PIONEER III (6 DEC. 1958)
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
110,000
RADIAL DISTANCE FROM CENTER OF EARTH–KM

Figure 2

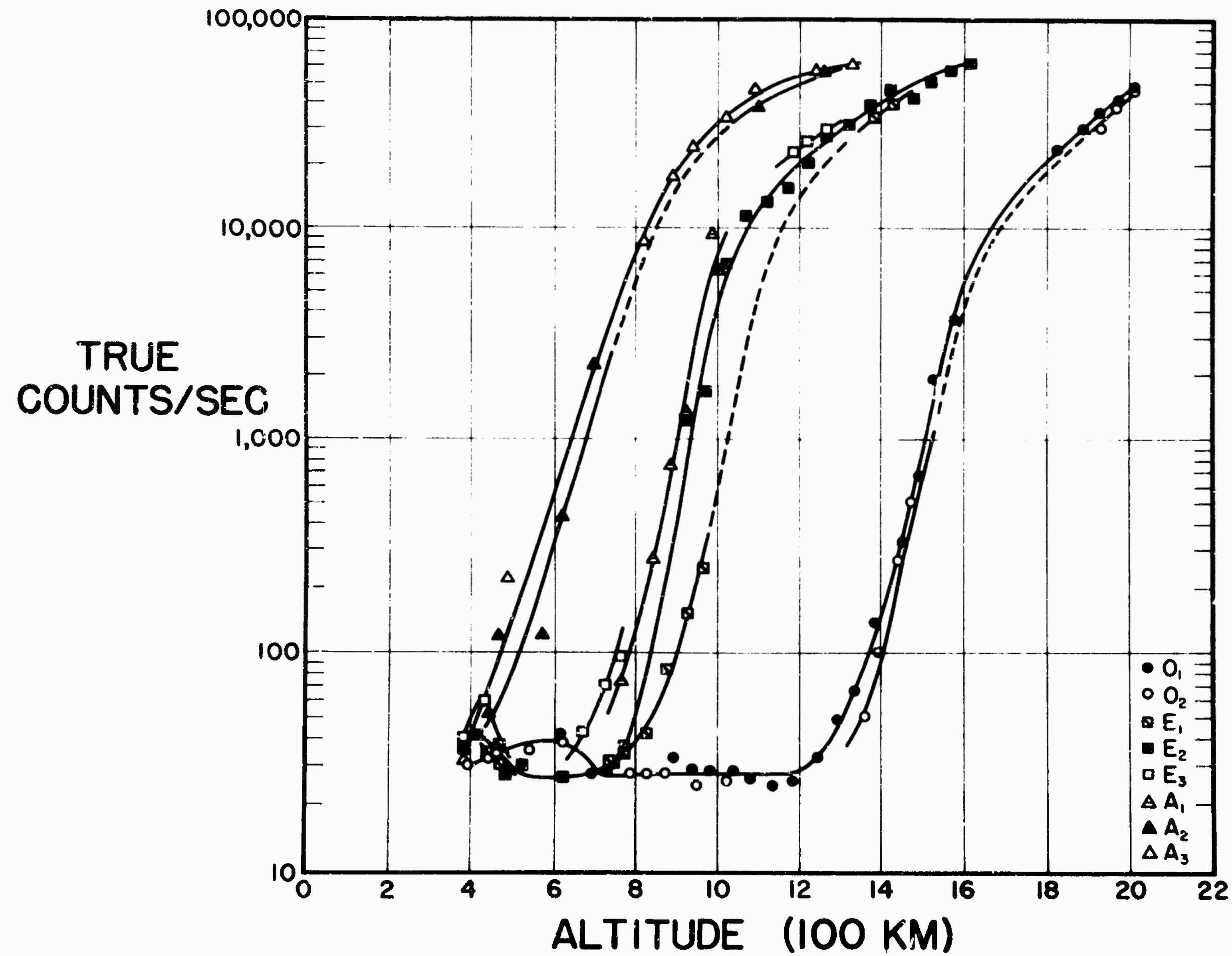

TRUE
COUNTS/SEC
100,000
10,000
1,000
100
10
0
2
4
6
8
10
12
14
16
18
20
22
ALTITUDE (100 KM)
$O_1$
$O_2$
$E_1$
$E_2$
$E_3$
$A_1$
$A_2$
$A_3$

Figure 3

LECTURES IN AEROSPACE MEDICINE

*JET STREAMS OF SOLAR PLASMA

Presented By

Professor Edward P. Ney

Institute of Technology

University of Minnesota

*This article will be published at a later date.

# LECTURES IN AEROSPACE MEDICINE

## BIO-RADIOLOGY IN SPACE AND IN THE LABORATORY

Presented By

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BIO-RADIOLOGY IN SPACE AND IN THE LABORATORY
by
Roger Wallace

## INTRODUCTION

From the point of view of a physicist, the most interesting problems of bioradiology in space naturally revolve around the question of the effect of the radiation dose received from cosmic ray particles. There are also doses received from solar electromagnetic radiation[1] and from radiation sources inside the space ship. The former can be controlled by simple shielding and the latter, while more difficult to shield against, are subject to engineering control. According to Schaefer[2] the dose received in the Van Allen belts, even with no shielding, is small for deep space flights with only two traversals. The critical danger arising from solar flare cosmic ray bursts has been investigated, and several papers have been published recently[3,4,5,6] including recommendations for dealing with this problem. Simons[7] has pointed out that in view of the lethal potentialities of the solar flares, measures must be taken to protect against them and that once these measures have been taken the radiation dose given to crew members during a flare, while perhaps still undesirably large, does not differ in its biological effect from doses received on earth, from shielded accelerators, reactors, or other man made and natural sources. In view of this, the dose inside the flare shield can be relegated to the status of an

engineering problem. Of course the intensities present in solar flares are not known with any great accuracy, and there are many unknowns still present, which must be cleared up by measurements before successful space flights can be made. These measurements are being pursued by many investigators, using rockets, balloons, satellites, and space probes.

Hence, if one plans ahead for space flight, one sees that it will be necessary to provide a small heavily shielded region in the space craft, with only a cramped space inside of this shield, in order to minimize its weight. This shield need not be occupied at all times. Hopefully, its occupancy may be as low as 10% of the time. When the space traveler is not huddled inside of the flare shield, he presumably will be in a thin pressure tank, which offers little protection against penetrating cosmic radiation. The dose rate from the ever-present background galactic cosmic rays is known to be about 26 mrep/24 hours, or 9.5 rep/year. The dependence of this dose on latitude and distance from the earth, together with the dose due to neutrons which are produced by these galactic cosmic rays in the atmosphere and then diffuse back up into space is shown in Fig. 1. It is seen that the geomagnetic effect is largely wiped out at distances of three or four earth radii, and from that point out that the galactic cosmic ray background amounts to the 26 mrep/24 hours.

The astronaut then receives this irreducible dose while in the larger cockpit of the space ship, or outside on the surface of the moon or an

appropriate planet, such as Mars. The last remaining question is whether the 26 mrep/24 hours can be converted to rem dose by multiplying by a reasonably small RBE such as slightly more than 1 up to 10. It is probable that this can be done, and that residence outside of the flare shield does not offer any serious radiation problems.

The use of an RBE between 1 and 10 is certainly justified for the proton cosmic ray component. The last remaining question hinges on the RBE of the heavy fragments present in cosmic rays. Much physical and biological work has been done on heavy ions by many investigators. The high charges present on the heavy ions produce densely ionizing tracks in materials which they strike, and there is a question whether a single particle may cause a gross biological effect, for example in the brain or other biological system. It is not the purpose of this paper to discuss this latter point in any detail, but to try to gather together some of the large amount of published material which is now available on the subject of heavy ions, since they are at present still to some extent an unknown in the astronaut radiation problem, and adequate earth or space experimental facilities are not now available.

## THE PASSAGE OF HEAVY IONS THROUGH MATTER

The first indication that ions heavier than protons are present in the primary cosmic radiation was secured from observations of wide, densely

ionizing tracks in emulsions flown just below the top of the atmosphere.[10] Since the Z of a particle can be identified by an examination of its track of developed silver grains in nuclear emulsion, it was soon realized that carbon, nitrogen, and oxygen, as well as heavier ions up to iron, were present in decreasing numbers, with increasing Z. The number of lithium, berylium, and boron ions, or their absence, has remained a problem to cosmic ray physicists to this day. The change of the intensity of the heavy ions with the latitude at which they are measured caused by the earth's magnetic field allows their energy spectrum as well as that of the primary protons to be measured. This use of the earth's field as a large spectrometer yields the results shown in Fig. 2. The equations for the spectra are given in Table I[11]. It is seen that the spectral shape for the heavy ions is very similar to that for protons. This similarity of spectrum offers some difficulty of explanation. It tends to favor those theories of cosmic ray origin in which the acceleration process occurs in large bundles of plasma, or in shock waves, carrying along all the different ions with various values of Z together at the same velocity.

In evaluating the behavior of a heavy ion in a stopping medium, it is of first importance to know the charge state which the ion has at any part of its path. This charge state is usually not single valued, nor equal to Z. Furthermore, it changes with velocity. But the change in charge state with different stopping mediums, for a given velocity and density is quite small.

The charge state achieved should be thought of as the result of a competition between the loss and capture processes. The charge of any one ion fluctuates along its path, and eventually declines to zero as the end of the path is approached.

There is at present no rigorous theory that relates the velocity and charge state for a given ion in a given medium. An excellent review of the present theoretical situation has been given by Neufeld.[12] There have been three basic approaches to the problem. The earliest is that of Bohr[13] and Lamb[14]. It is assumed in the Bohr theory that an ion of large Z will lose all of its electrons which have orbital velocities less than its translational velocity through the stopping medium. This is certainly qualitatively true. Bohr argued that the slower and less firmly bound electrons are the most easily removed, and that in the inverse process electrons are more likely to be captured into orbits whose characteristic velocity is close to that of the moving ion through the medium.

Lamb stated the stripping condition in another way, that the moving ion is stripped down of its outermost electrons until the ionization potential of the next stage of ionization is greater than the kinetic energy of electrons bombarding the ion with the velocity of translation of the ion through the medium.

In order to check the validity of the Bohr-Lamb criteria it is necessary to have values for the electron velocities in heavy ions. These have been

given by the Bohr[15] model, the Knipp and Teller[16] model, and by the various refinements of the work of Lisitzin[17-21]. The material pertinent to the heavy ion problem from the last five references has been summarized by Neufeld[12,22]. At best, the experimentally measured values for the ionic charges as a function of velocity agree only roughly with those predicted from the theories of Bohr and Lamb. Furthermore, the species of the stopping medium and its density have not been considered at all.

In a gas Lassen[23,24,25] has shown that fission fragments have a higher ionization in argon than in helium. On the other hand Hubbard[26] did not find this effect with either oxygen or neon passing through hydrogen, helium, nitrogen, or argon. It is possible that the effect is too small with oxygen or neon for him to have seen it. In a solid or a liquid, the effect of the stopping medium on the charge state of the traversing ion is less than in a gas. For fission fragments the variation is less than 10% in various media. Surprisingly, when nickel (Z=28) and Formvar (Z=4) are compared[27,28,29] as stopping media, the stripping of heavy ions is greater in the Formvar.

The average charge of an ion increases with the pressure of a stopping gas, up to a plateau value. This effect depends on the relative length of the average time between successive charge exchange collisions compared to the average time for radiation of the ion in an excited state. If the collisions are infrequent, electrons that have been excited, but not separated completely from the ion can radiate and drop back to their original

state. If the collisions are closer together in time than the de-excitation processes, the electrons are successively excited and eventually removed from this ion.

It should be realized at this point that in an ion that is in equilibrium with its stripping medium, having been several times ionized, and yet having several electrons remaining, these remaining electrons are not in their ground states, but are in a continually perturbed state of excitation. One of the difficulties that is encountered in heavy ion theory is that the ions are actually in excited states whenever moving inside a medium. So far all theories have been for ground state ions. It would be desirable, in order to use the Bohr-Lamb theories in a solid or liquid, to know the distribution of electron orbital velocities or energies in an ion that is continually perturbed by collisions at a relatively high frequency. Neufeld[30] considers the effect of the moving ion on the medium and the back reaction of the rearrangement of the electrons of the medium on the electrons of the ion. This refinement has the advantage of being applicable to any ion while the Bohr theory is only applicable to any ion while the Bohr theory is only applicable to heavy ions.

An alternate approach to the theoretical understanding of the passage of the heavy ions through a medium has been suggested by Bell[31]. He estimated the charge on a moving ion by considering the detailed balance of the capture and loss processes. Assuming that only one electron is lost

or gained in any one collision, Bell has used as the condition for equilibrium between a heavy ion and its medium:

$$\sigma_C(Z^*_{Av},V) \cong \sigma_L(Z^*_{Av},V) \qquad (1)$$

where $\sigma_C$ and $\sigma_L$ are the capture and loss cross sections (for one electron) for an ion with average charge $Z^*_{Av}$ and velocity V. The charges for fission fragments, computed on this basis by Bell, and the experimental values of Lassen[23,24] are shown in Table II. The modified values of Lassen shows in the table are corrections made by Bell for a 6% momentum difference between Lassen's measurements and Bell's calculations. This method has been refined by Gluckstern[32], who instead of using for $\sigma_C$ the sum of individual capture cross sections into the various states available has used the capture cross section for any electron. This decreases the value of the cross section by about 40%. In addition, Gluckstern modified the Bell statistical model so that it would apply to light ions where there are too few electrons for a statistical model. This was done by substituting for the the Thomas-Fermi distribution one in which the electrons are located in concentric shells with radii corresponding to the known ionization potentials.

The capture and loss cross-sections calculated by Gluckstern for oxygen, neon, phosphorus and argon as functions of velocity are shown in Figs. 3-6. The calculated charge distribution on oxygen and neon ions in argon compared to the experimental values of Hubbard[26] are seen in **Figs.** 9

and 10 for two different energies. It is seen that the agreement is good. The gradual increase in average ion charge with increasing velocity is compared to the experimental results of Reynolds[27,28,29], Stephens[33], and Hubbard[26], in Fig. 7. The agreement of theory and experiment is seen to be better than 0.5 charge states in all cases.

The experimentally measured (Hubbard[26]) build up of the +3, +4, +5, and +6 charge states of 8.7 Mev oxygen ions in argon is seen in Fig. 8. The solid lines in Fig. 8D are least squares fits to the experimental data, not the theoretical values. Gluckstern[32] had used these values and, for example, the rate of loss of +4 ions with depth is given by:

$$\frac{dN_4}{dx} = - \sigma_{43}N_4 - \sigma_{45}N_5 + \sigma_{34}N_3 + \sigma_{54}N_5 \qquad (2)$$

From this relation one can obtain the experimental cross-sections given in Table III for comparison to the theoretical values from Fig. 3. The agreement is good, except that the capture cross sections for low-charge states are measured to be smaller than those calculated.

In view of the fair success of the capture and loss model, the following conclusions from it are of interest:

a. The capture cross section is independent of the particular ion, and is proportional to $Z^{*2}/V^{3.5}$;

b. The loss cross sections have maxima and are sensitive to the model of ion used.

c. The charge distributions do not change much in width with velocity.

d. The average charge is independent of the stripper material.

e. The average charge increases with velocity until the K shell begins to ionize and then levels off.

f. Possibly double and triple ionization cross sections and capture cross sections should be included in this analysis.

There are indications that the double ionization process may be as much as 50% of the single ionization processes. This would force a modification of the theoretical cross sections for single events given in Figs. 3, 4, 5, and 6.

Some of the above features are illustrated in the experimental charge distributions for oxygen and neon measured by Hubbard[26] and shown in Figs. 11 and 12. Additional detailed experimental work with results parallelling those given in Figs. 8, 11, and 12 is described by Nikolaev[34].

## RANGE-ENERGY AND STOPPING POWER DATA

Many experiments have been conducted to measure the ranges of heavy ions of different energies in a variety of materials. The authors (references 35-40) who have reported on these experiments have not all plotted their data in the same way, some preferring, for example, range vs. energy, others E/A vs. range, and still others condensing the range by multiplying it by $Z^2/A$ of the heavy ion, and plotting this, either as the independent or dependent variable. Because of the practical usefulness of this information, the curves given in Figures 11-20 have been replotted wherever this was

necessary to give consistent data. Thus, ranges for all materials except emulsion are given in units of $mg/cm^2$. Ranges of ions in emulsion are given in microns. Energies, in all cases, refer to total ion energy, rather than to energy per nucleon (E/A).

Somewhat less information on stopping power as a function of range or energy or velocity is available. Here, too, one finds considerable variety in the way in which data is presented by different authors. Accordingly, Figures 21 to 31 have, with the exception of Figures 27 and 31, been replotted to give stopping power as dE/dx, Mev/micron, for ions in emulsion, and as dE/ρdx, Mev/ $(mg/cm^2)$, for ions in all other materials. The very extensive work on tissue by Neufeld and Snyder,[41, 42] shown in part in Figures 29 and 30, should be especially noted, since this is the basis for the biological evaluation of the effects of heavy ions.

## THE PRESENT EXPERIMENTS

The pure physics of the interaction of heavy ions with matter has now been outlined and the literature available reviewed. At present experimental work is proceeding on both the biological and physical problems at the two heavy ion linear accelerators in the United States (Yale University, and Lawrence Radiation Laboratory, Berkeley). There is also a heavy ion accelerator at Krakov in the USSR. In addition, work is being carried on under much more difficult conditions in balloons, rockets, and satellites. Unfortunately, the heavy ion accelerators available at present are only capable of imparting about 10 Mev per nucleon to their heavy ions. This is a very modest energy when compared to the energy of the heavy cosmic ray primaries. Only a very limited range of biological samples can be

available range-energy results. These are contained in references 35 through 40. Unfortunately, these authors have not all plotted their data in the same way, some prefering range vs. energy, others energy vs. range and others condensing the range by multiplying it by $Z^2/A$ of the heavy ion, and plotting this, either as the independent or dependent variable.

Somewhat less data on stopping power as a function of range or energy or velocity is available. This material is outlined in Table V in the same way that range data was in Table IV. The very extensive work on tissue by Neufeld[41] and Snyder[42] should be noted, since this is the basis for the biological evaluation of the effects of heavy ions.

## THE PRESENT EXPERIMENTS

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irradiated with these low energy ions, since the ranges of all Hilac ions in tissue are less than 1 mm. Enzymes, bacteriophage, bacteria, and yeast cells have been studied as described by Brustad[43], Hutchinson[44,45] and many others listed in Reference 43. There have been three reviews by Zirkle[46], Zelle[47], and Howard-Flanders[48] of radiobiological effects as a function of the ionization density of the radiations.

A. Accelerator studies:

The present accelerators can give monoenergetic intense beams of ions with Z as high as 18. It is possible to quickly change from one ion to another which is very convenient experimentally, and perhaps reduces some systematic errors. Most studies on biological systems have been aimed at measuring changes in radiosensitivity with LET*. The experimental set up at the exit of the Hilac is seen in Fig. 32 and the details of a sample handling unit are shown in Fig. 33, from Brustad[43]. The Bragg curves of Fig. 31 were obtained with this equipment.

It is concluded by Brustad[43] that, in the case of several enzymes irradiated in the dry state in vacuum, in addition to the effect of the LET of the bombarding ions, the radiosensitivity also depends on admixtures of foreign materials, pH of the medium from which the samples are prepared,

*LET = Linear Energy Transfer, is the energy actually absorbed locally by the medium, as contrasted to dE/dx, which is the energy lost by the moving ion in an interval dx by perhaps not absorbed by the medium in dx but at a distance from dx.

the buffer in which the samples are resuspended after irradiation, the temperature during exposure, oxygen or lack of it during exposure, and post irradiation gas treatment. There is a migration of the energy deposited by the heavy ions between adjacent enzyme molecules, which depends on several factors There are problems of sample preparation that may influence some of the experimental results. The corrections which must be made for $\delta$ rays are beset with problems. There have been three approaches to the $\delta$ ray correction by Lea[49], Pollard[50], and Fluke[51]. An inactivation cross-section $\sigma$ can be defined by:

$$\frac{n}{n_o} = e^{-\sigma D} \qquad (3)$$

where $n/n_o$ is the fraction of the enzymatic activity remaining after a dose of D particles/$cm^2$. The dependence of $\sigma$ on LET for three enzymes is seen in Fig. 34. Successively more complicated systems, Bacteriophage, both wet and dry, Bacteria, in $N_2$ and $O_2$ atmospheres, haploid yeast, in $N_2$ and $O_2$ atmospheres and diploid yeast have all been investigated, with the results described in Reference 43.

Experiments which are closer to the problem of space flight have been reviewed by Simons[52] in which he limited his considerations to those experiments which bear on the immediate medical problem of heavy ion damage. Figure 35, based on Simons' data, shows the number of ion pairs formed per micron of path in water, or approximately for tissue equivalent

material, plotted against the range of the particle in water. Carbon, neon and iron are given as separate curves. The iso-energy curves are also shown, so this figure contains a condensation of almost all the important information available on the interaction of heavy ions with tissue, except of course for the radial variation of track ionization. The variation of the energy of the particles in the region of the earth during the sun spot cycle is indicated. Outside of a few earth radii, the earth's field becomes quite small, and this magnetic cutoff is absent, allowing particles down to energies which can pass through the much weaker solar magnetic field. The regions in which tracks terminate by thindown rather than nuclear collision are indicated. This distinction probably has considerable biological significance. The region of cosmic ray hits as defined by Schaefer is shown. The three regions which differ in the qualitative appearance of their radial distribution of ionization, are roughly shown. Finally the region presently covered by accelerators, and also the region covered by one projected future accelerator is indicated.

Unfortunately no experiments performed so far in balloons or rockets have been arranged to resolve the three types of radiation pattern indicated in the figure. It is clear that a machine going to 500 Mev/nucleon would have great experimental advantages, in that it would allow all three of the different delta ray pattern regions to be investigated. It would seem that going much beyond 500 Mev/nucleon would be of less interest, since the heavy

ion track patterns give way to collisions producing stars which may not be very different from those provided by proton accelerators already available in this region. The stars made by heavy ion nuclear collisions in tissue would, of course, have more prongs than those made by protons. This may have further biological implications, so that there may be interest in heavy ions at even higher energies than 500 Mev, but this would seem to be a present practical goal which would be a real challenge to the accelerator designer. An additional strong reason for the construction of a new accelerator, compared to additional experimental efforts to use cosmic rays as a source of heavy ions, is that in addition to the usual cosmic ray problem of not knowing when or where or what kind of particle or from what direction it will arrive, the intensity is very low. The fact that the intensity is low is reassuring in assessing the potential danger for short space flights. Above 100,000 ft. there is about 1 "hit" or thin-down track (as defined by Schaefer and indicated in Figure 35) per $cm^3$ tissue per 24 hours. This rate has forced experimenters to select biological situations which offer a possibility of seeing results in spite of the very small number of heavy ions present. The most famous experiments have been the "mouse cloud chamber" work done by Chase (references 3 through 17 in our reference 52). During a total of 4525 mouse hours above 90,000 feet, grey streaks were observed in the mouse hair, giving one identifiable grey streak per 38 mouse days. The streaks are interpreted as being caused by

heavy ion damage to the mouse skin, by a particle traveling roughly parallel to it.

Mouse hair follicles are separated by about 100 microns, yet the radial extent of a heavy primary track is of the order of 10 microns. It would seem that more work is called for to resolve this apparent discrepancy. It seems inescapable that the grey spots of hair and streaks are due to single ionization events. There is some evidence that the effect of these single ionizing particles is transmitted to the affected follicles by their supporting cells.

## CONCLUSION

At the present time the physicist's understanding of heavy ions is theoretically on a fair basis. The technology for producing them and accelerating them is well developed, although the maximum energies now available are dissappointingly small. The biological experiments indicate that heavy ions produce quite different effects from x-rays. There is evidence for single hit large effects in addition to the mouse hair greying, such as the survival of artemia eggs and the forward mutation of barley seeds. The possibility of new variables, such as a variable radial charge distribution, becoming available in the bioradiology of heavy ions that are not available in presently available radiation sources, argues strongly for the early construction of new heavy ion accelerators of high energy.

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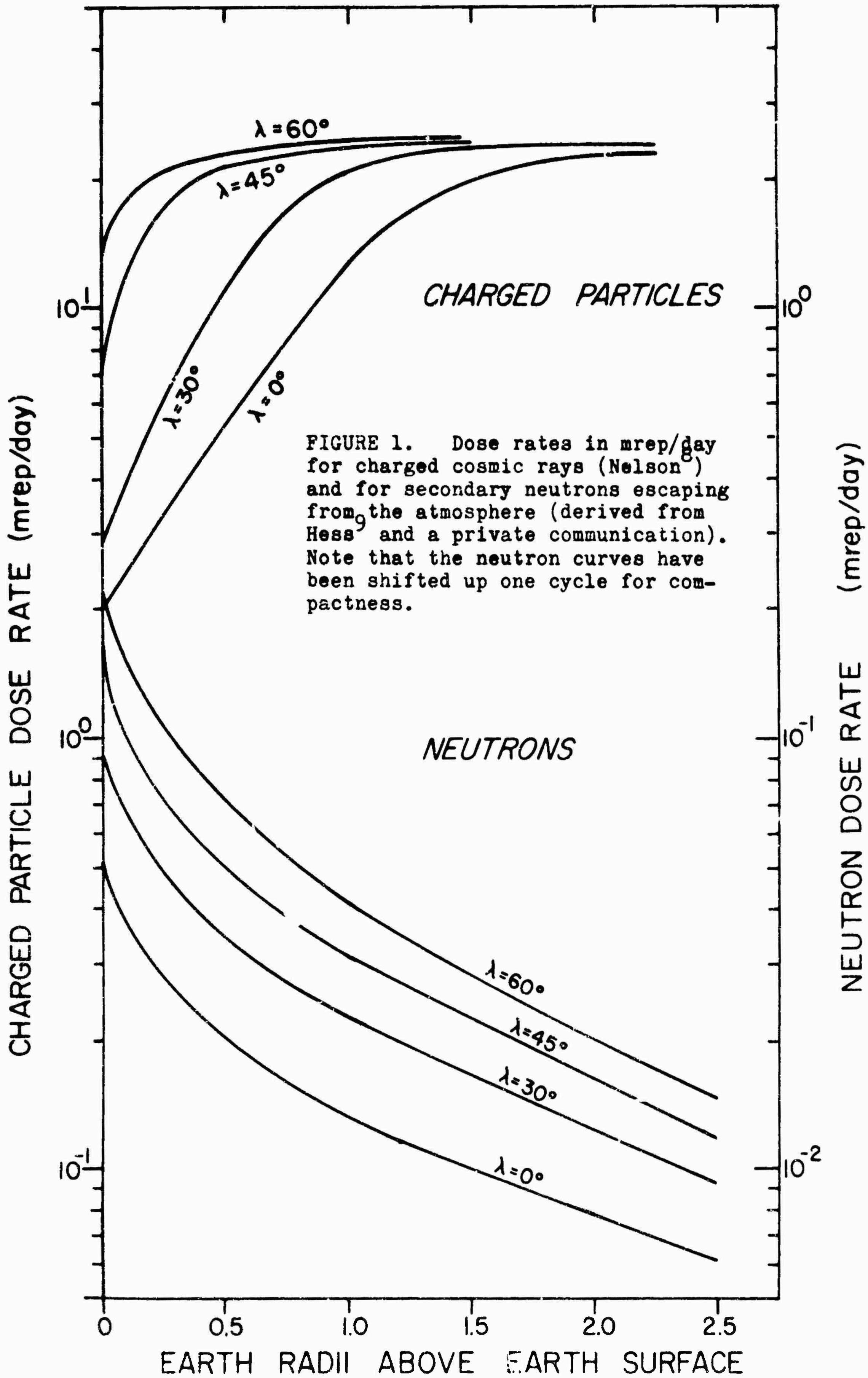


FIGURE 1. Dose rates in mrep/day for charged cosmic rays (Nelson[8]) and for secondary neutrons escaping from the atmosphere (derived from Hess[9] and a private communication). Note that the neutron curves have been shifted up one cycle for compactness.

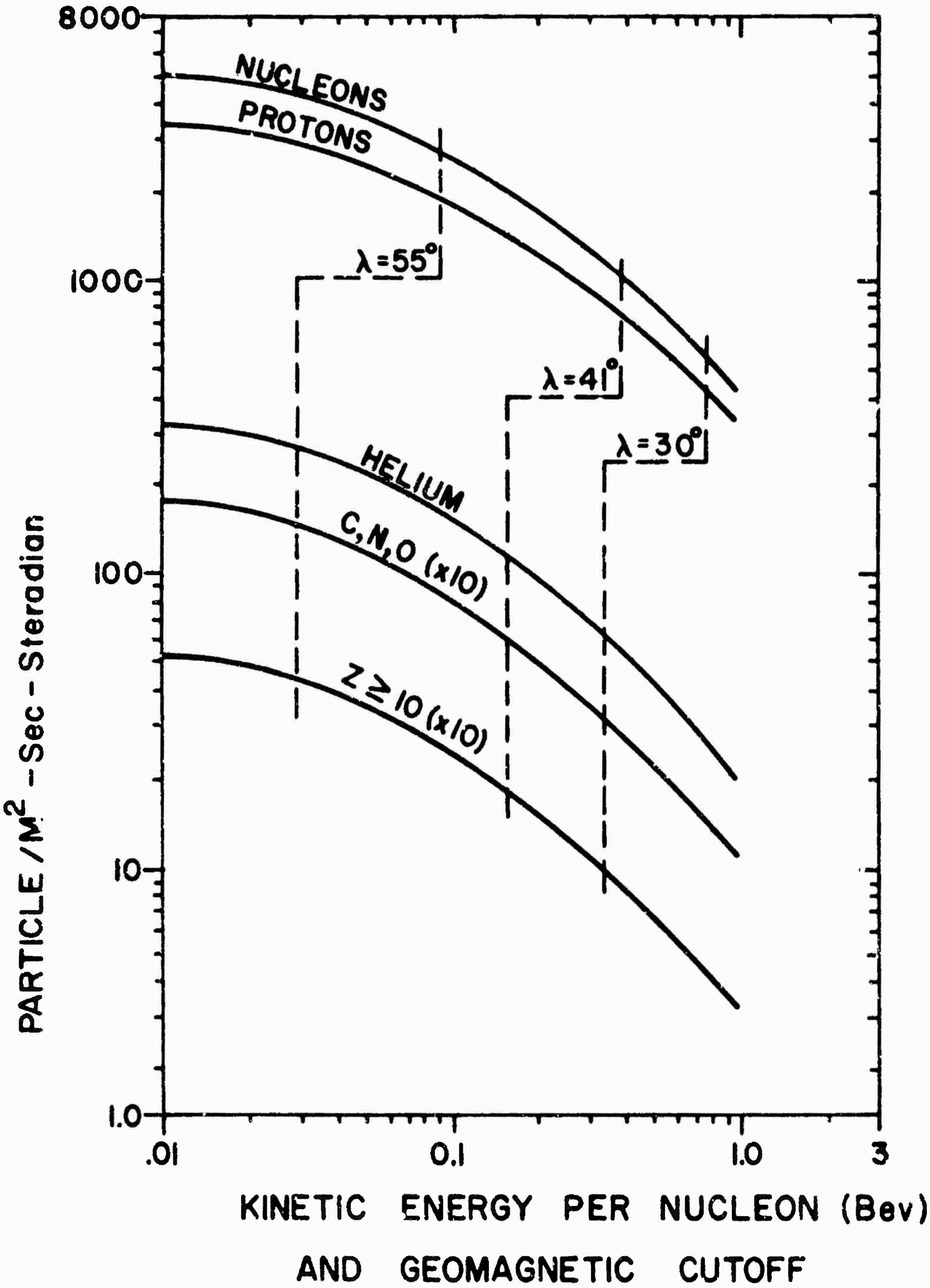


FIGURE 2. Integral energy spectrum of primary cosmic rays, separated into four constituents: nucleons as a whole; protons; helium; carbon, nitrogen, and oxygen, and Z = 10. The magnetic cutoffs for 30, 41, and 55 degrees geomagnetic latitude are shown. The cutoff at the equator for protons is 15 Bev.

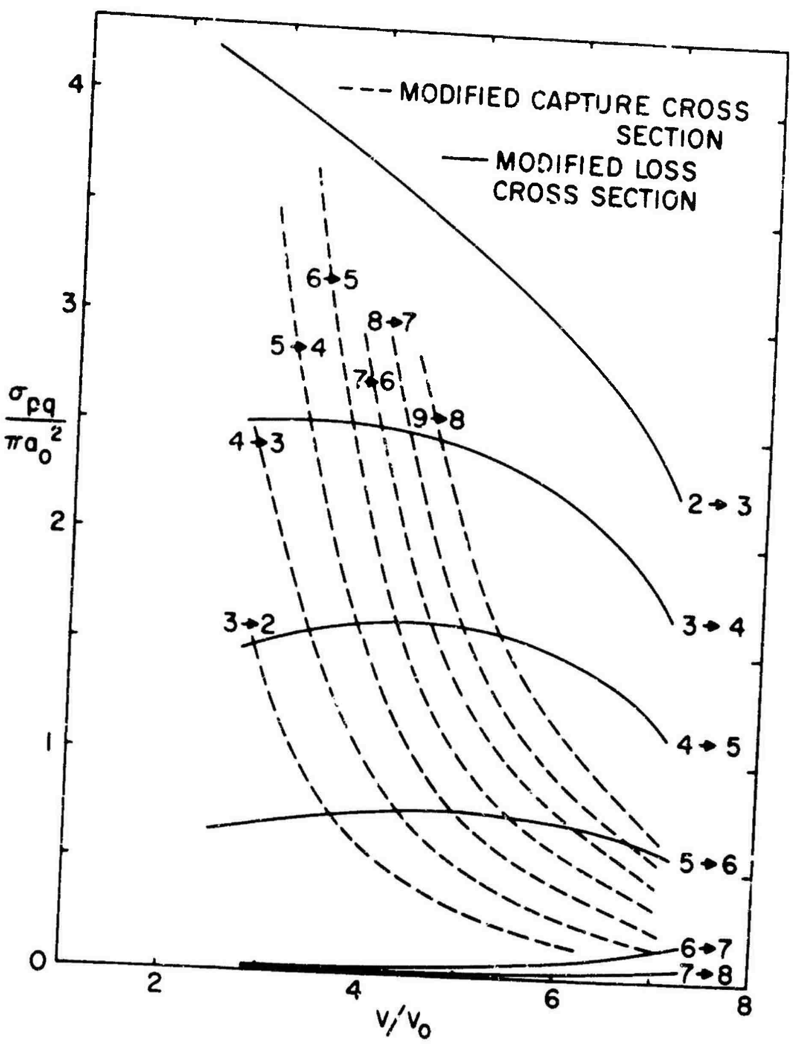


FIGURE 3. Modified capture and loss cross sections for oxygen ions in argon ($Z_2$=18).

$V_o$= c/137= 2.[illegible] x $10^8$ cm/sec;

$a_o$= $h/me^2$ = 0.53 x $10^{-8}$ cm;

$\pi a_o^2$ = 8.8 x $10^{-17}$ $cm^2$.

From Gluckstern (1954)

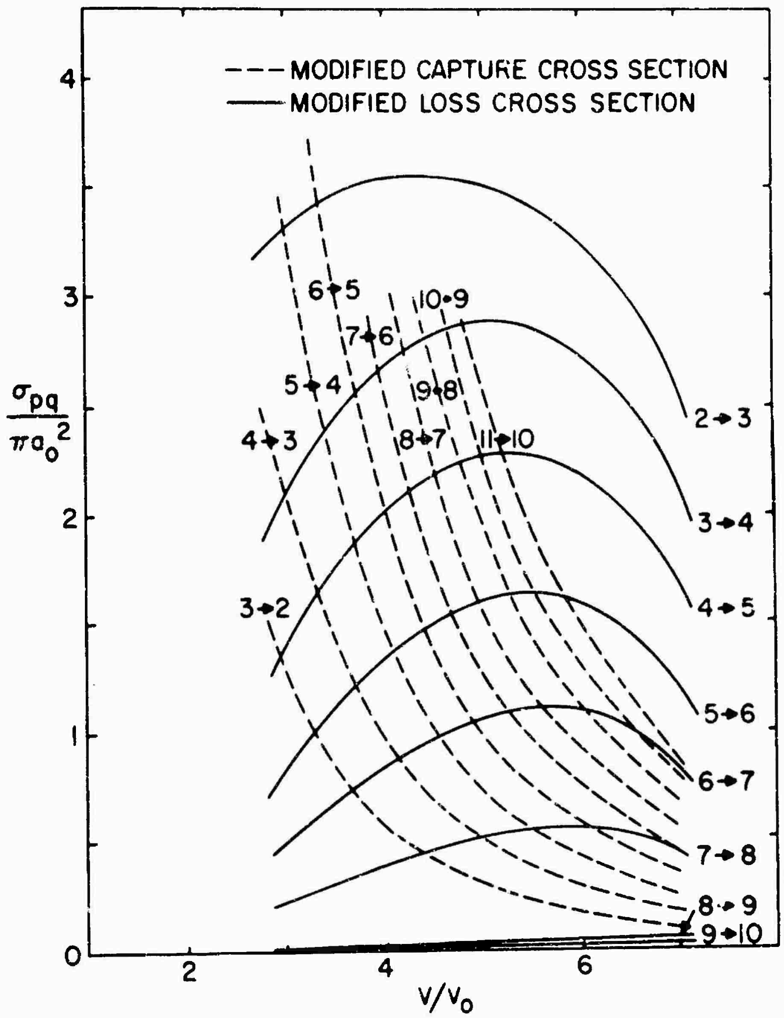


FIGURE 4. Modified capture and loss cross sections for neon ions in argon ($Z_2 = 18$). From Gluckstern (1954)

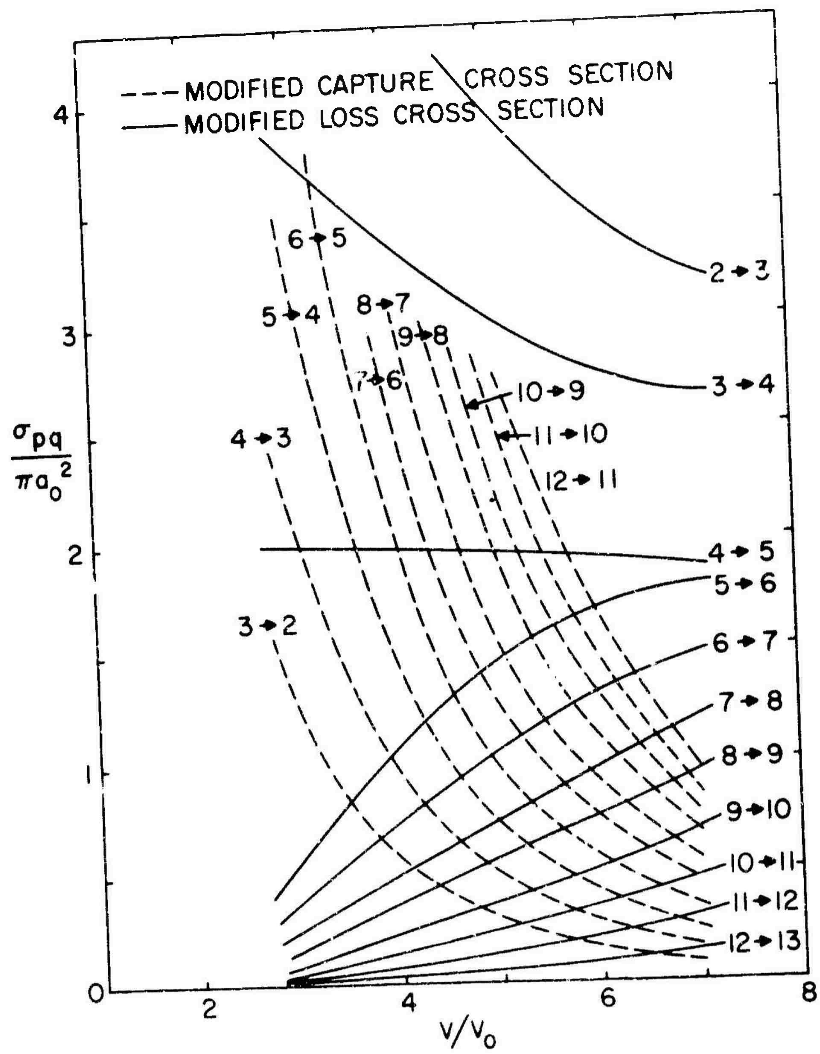


FIGURE 5. Modified capture and loss cross sections for phosphorus ions in argon ($Z_2$ = 18).

From Gluckstern (1954)

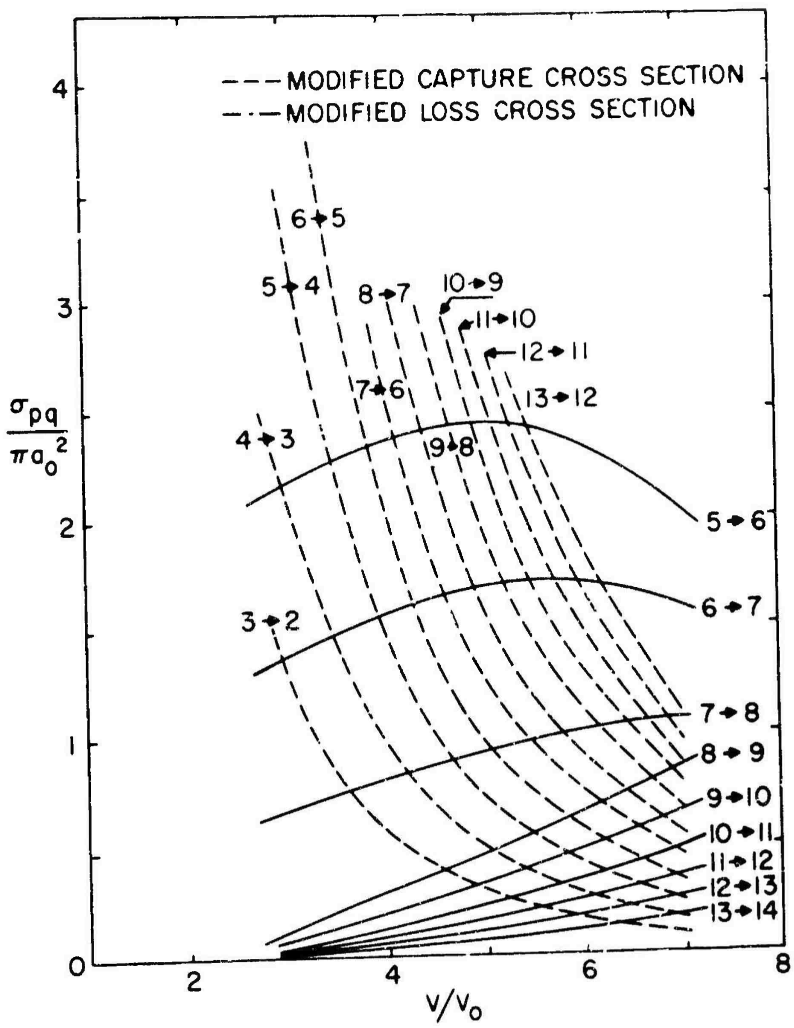


FIGURE 6. Modified capture and loss cross sections for argon ions in argon ($Z_2 = 18$).

$V_o = c/137 = 2.18 \times 10^8$ cm/sec;

$a_o = \hbar/me^2 = 0.53 \times 10^{-8}$ cm;

$a_o^2 = 8.8 \times 10^{-17}$ cm$^2$.

From Gluckstern (1954)

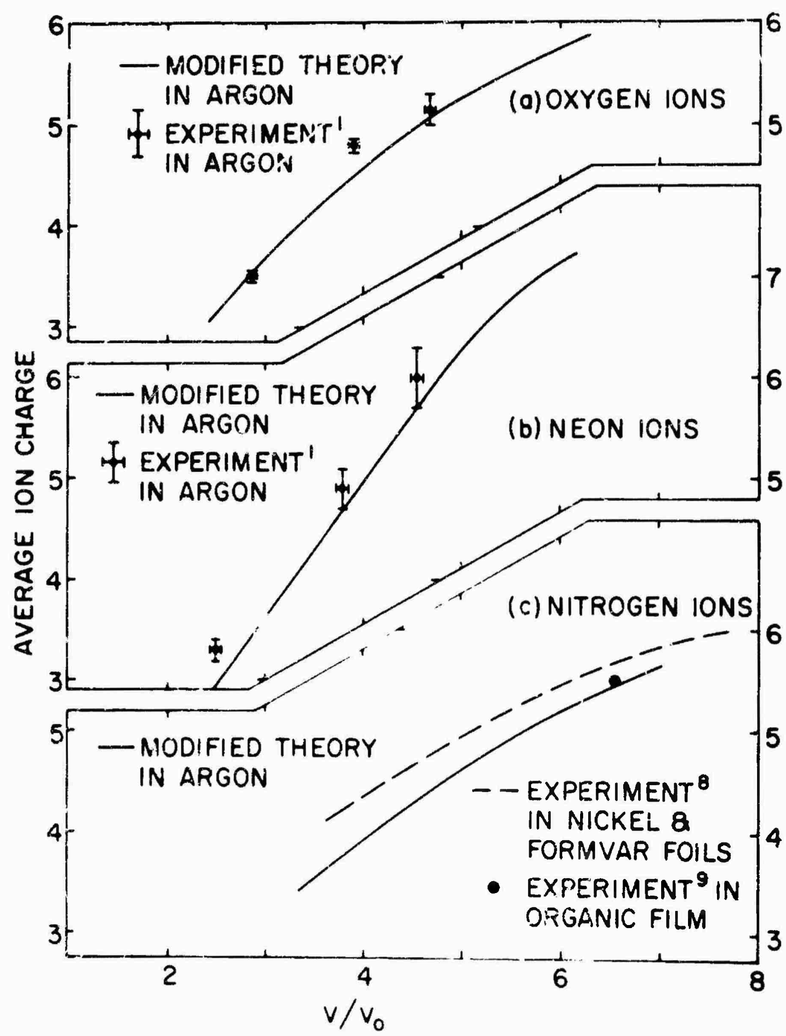


FIGURE 7. Average ion charge vs. ion velocity. From Gluckstern (1954).

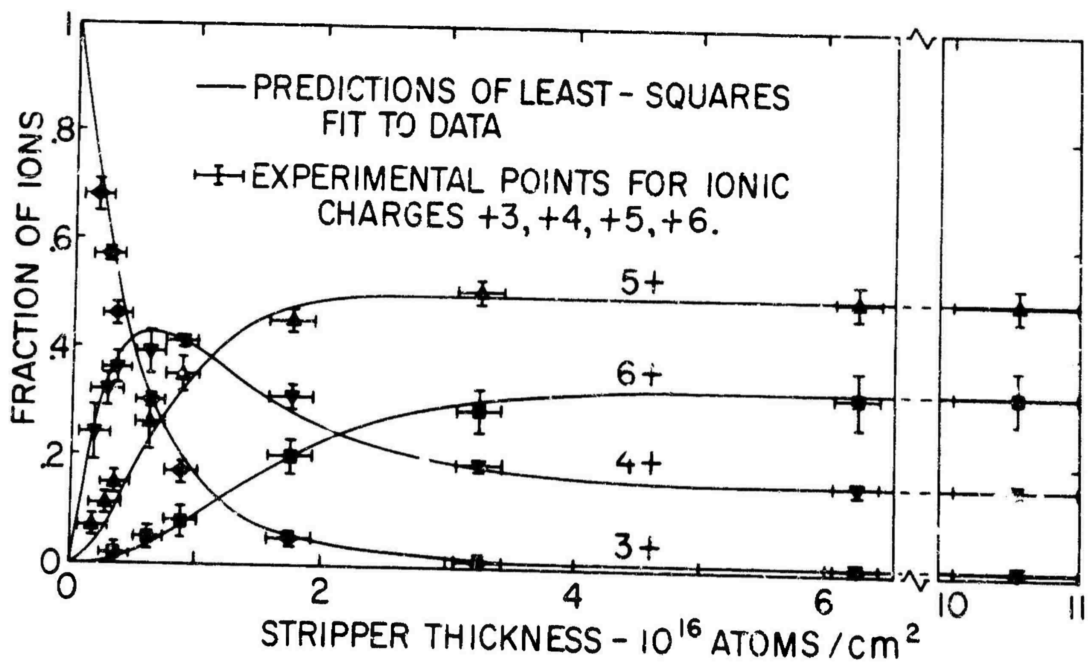


FIGURE 8. Charge distribution vs. stripper thickness for 8.7-Mev oxygen ions. From Gluckstern (1954).

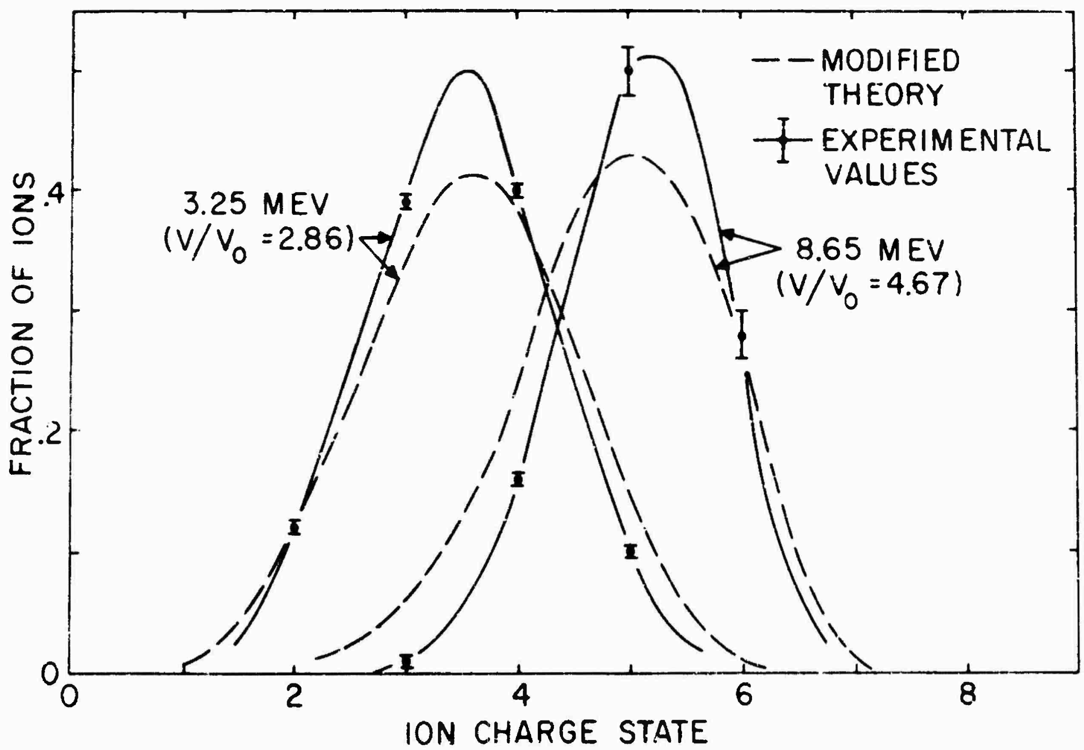


FIGURE 9. Charge distribution at equilibrium for oxygen ions in argon.

From Gluckstern (1954)

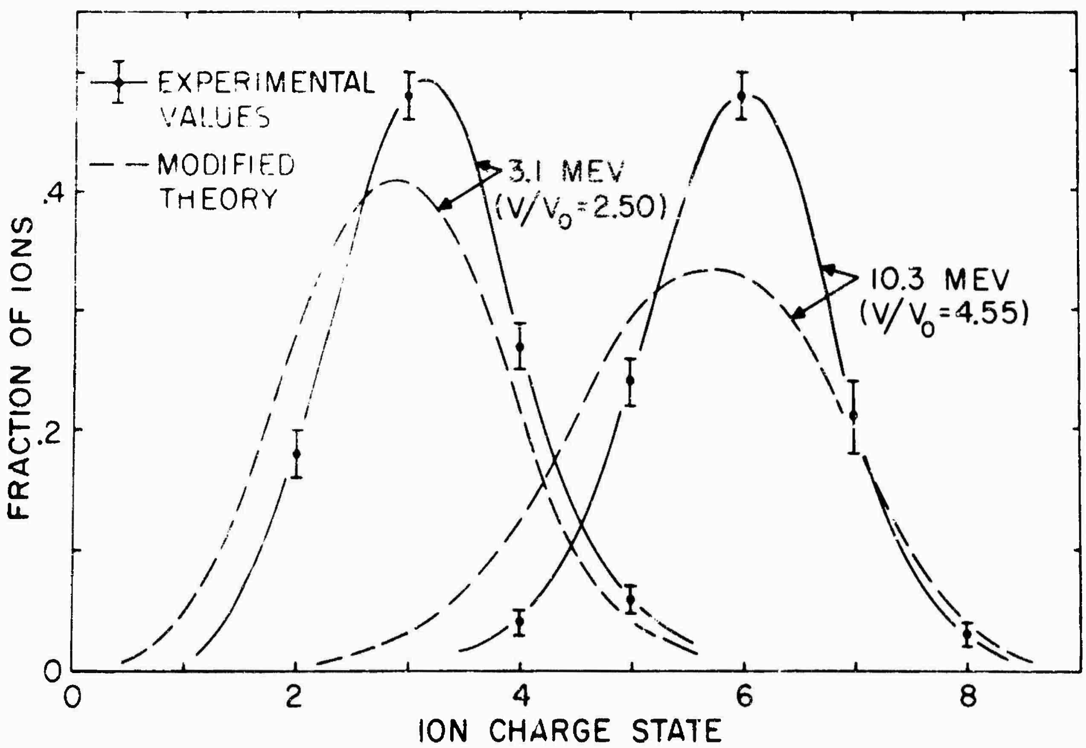


FIGURE 10. Charge distribution at equilibrium for neon ions in argon. From Gluckstern (1954).

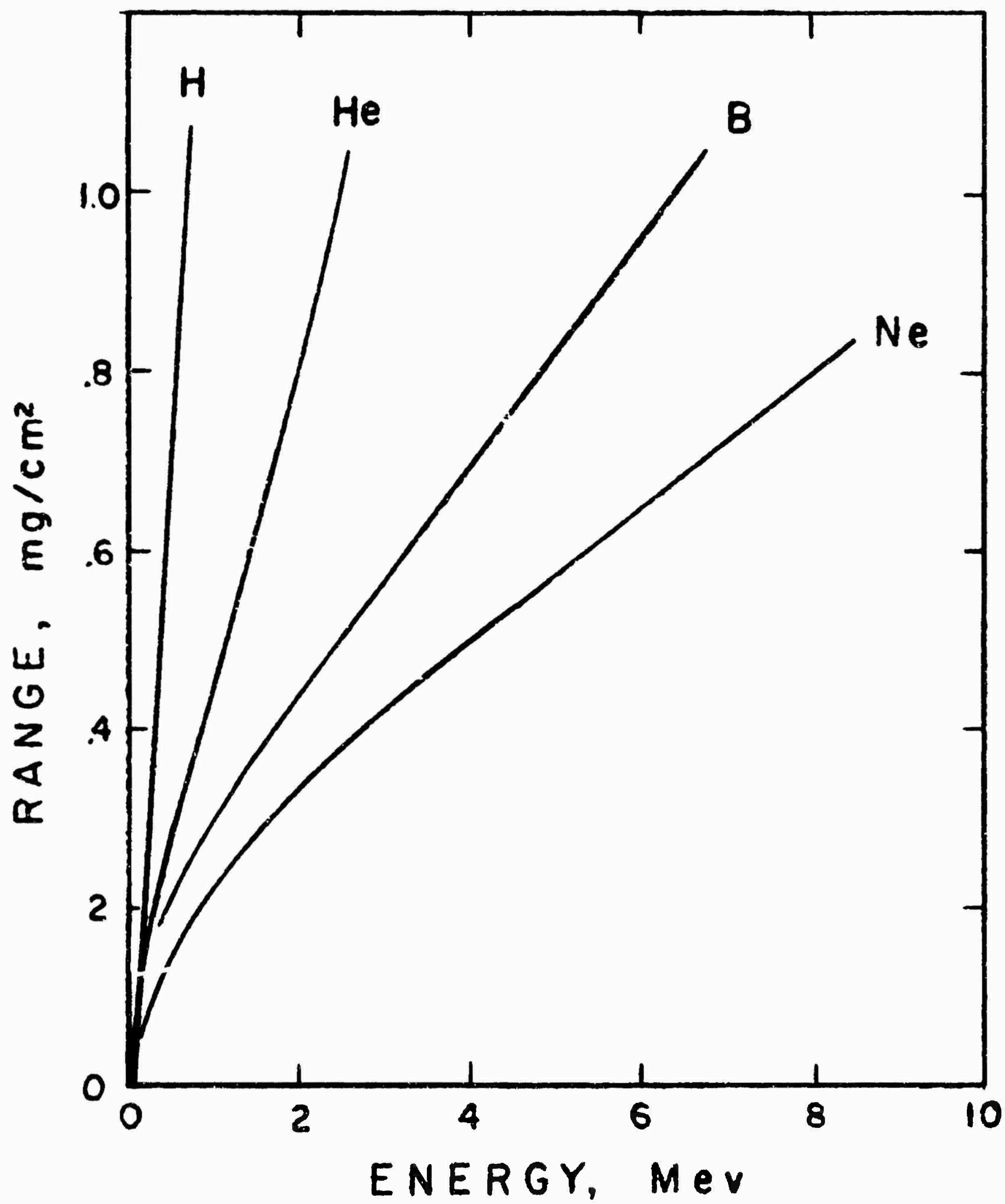


FIGURE 11. Ranges of ions in air at 760 mm., 20° C. ($\rho$ = 1.20 mg/cm$^3$). Redrawn from Teplova (1958).

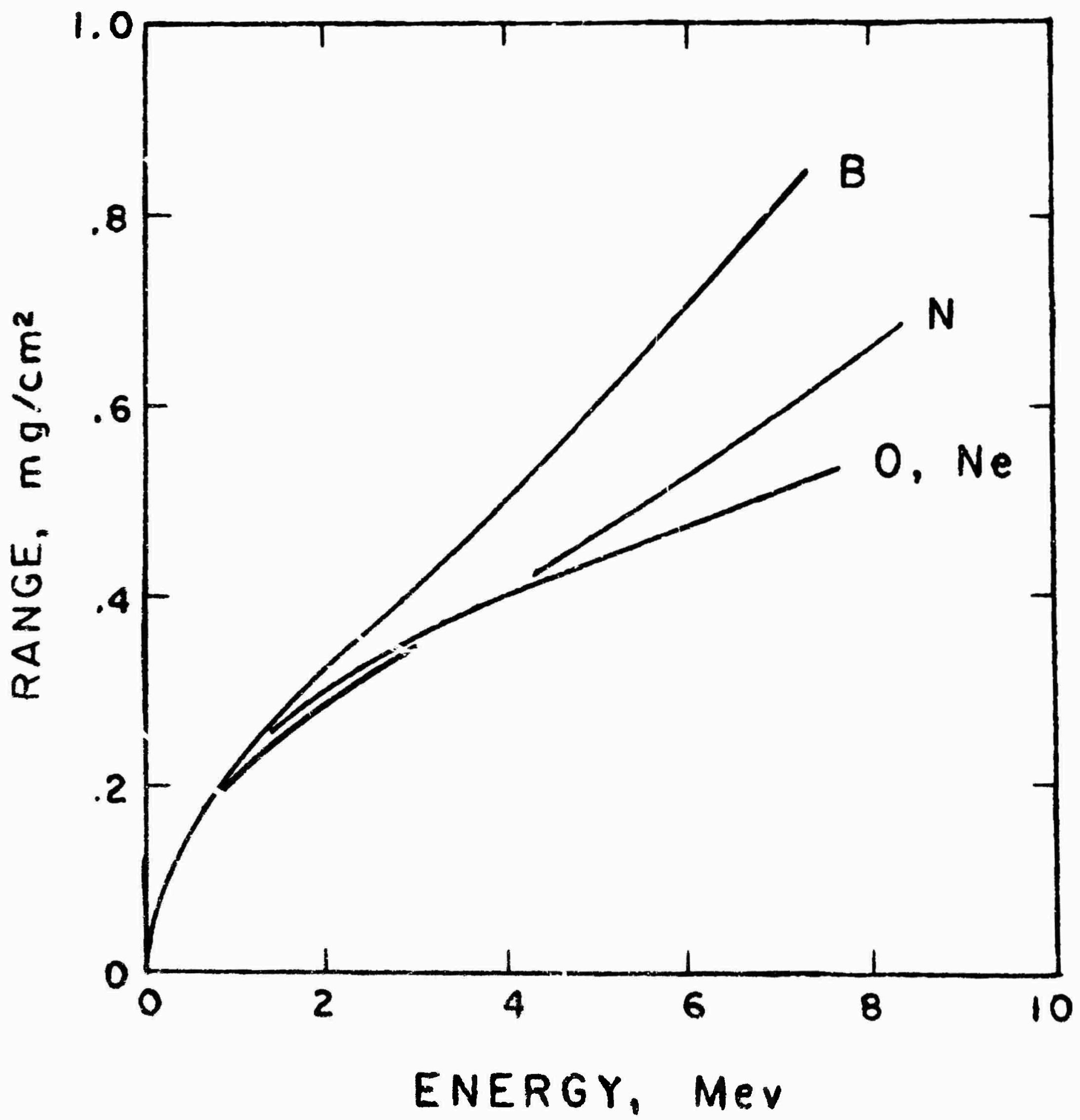


FIGURE 12. Ranges of ions in argon at 760 mm., 20° C. ( $\rho$ = 1.66 mg/cm$^3$). Redrawn from Teplova (1958).

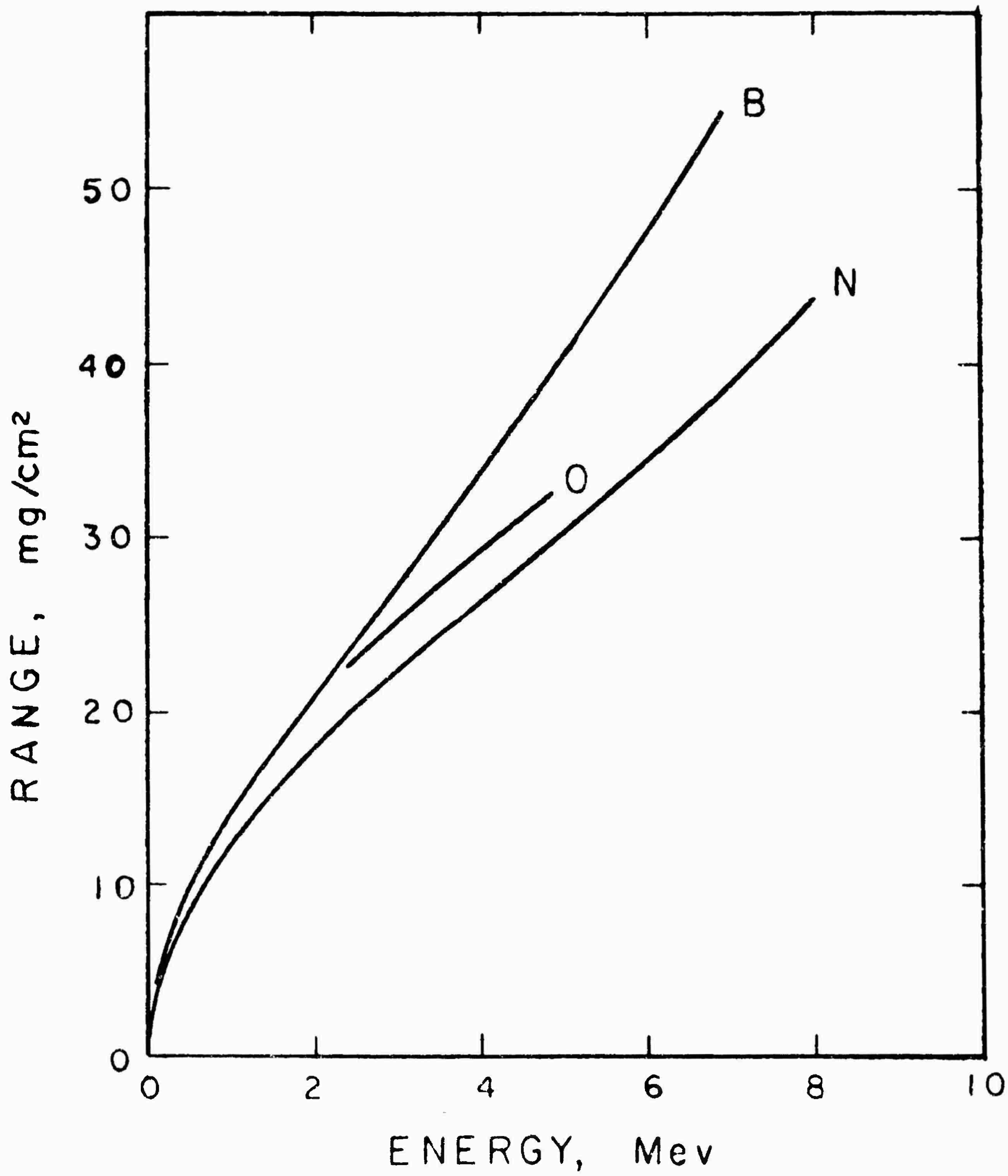


FIGURE 13. Ranges of ions in hydrogen at 760 mm., 20° C. ( $\rho$ = 0.08 mg/cm$^3$). Redrawn from Teplova (1958).

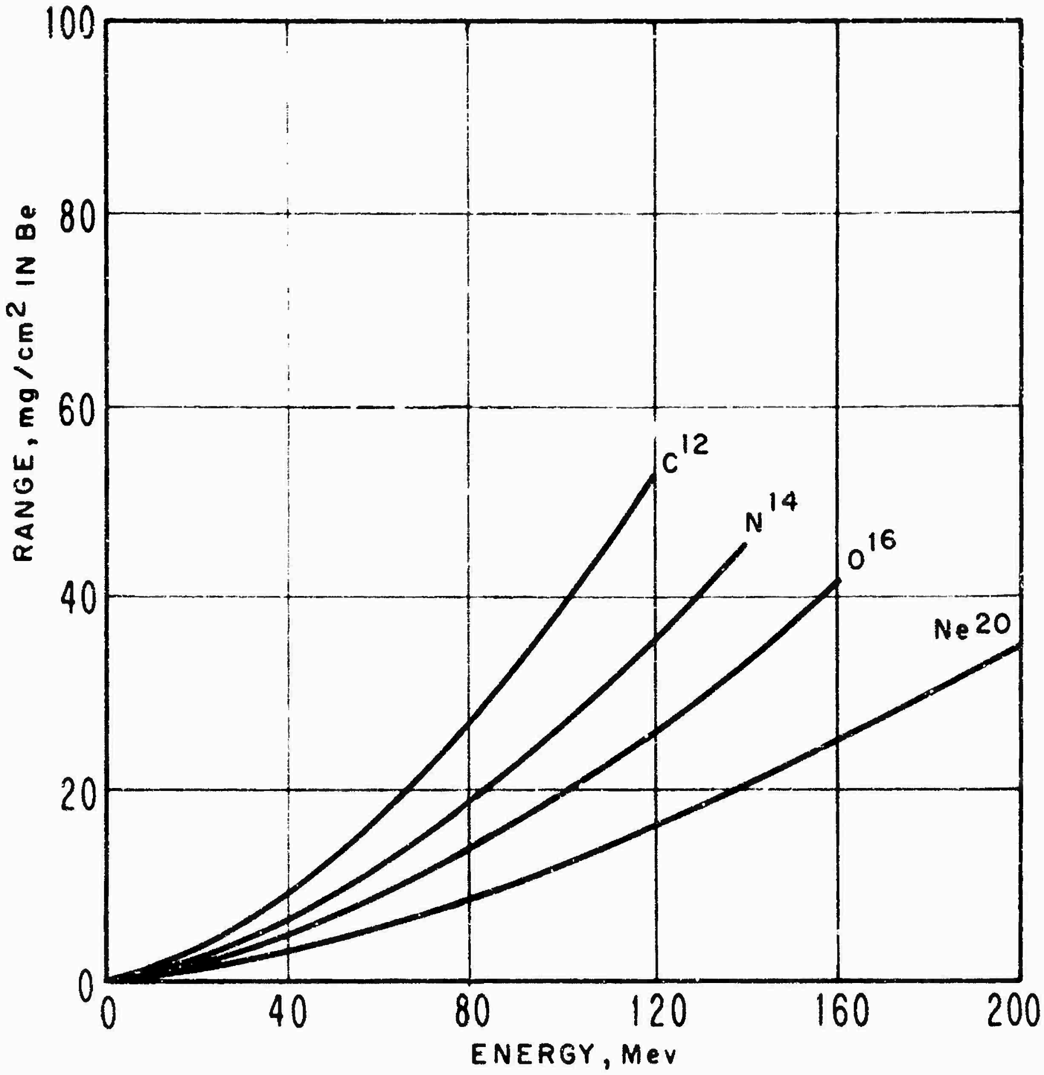


FIGURE 14. Ranges of ions in beryllium. Redrawn from Hubbard (1960).

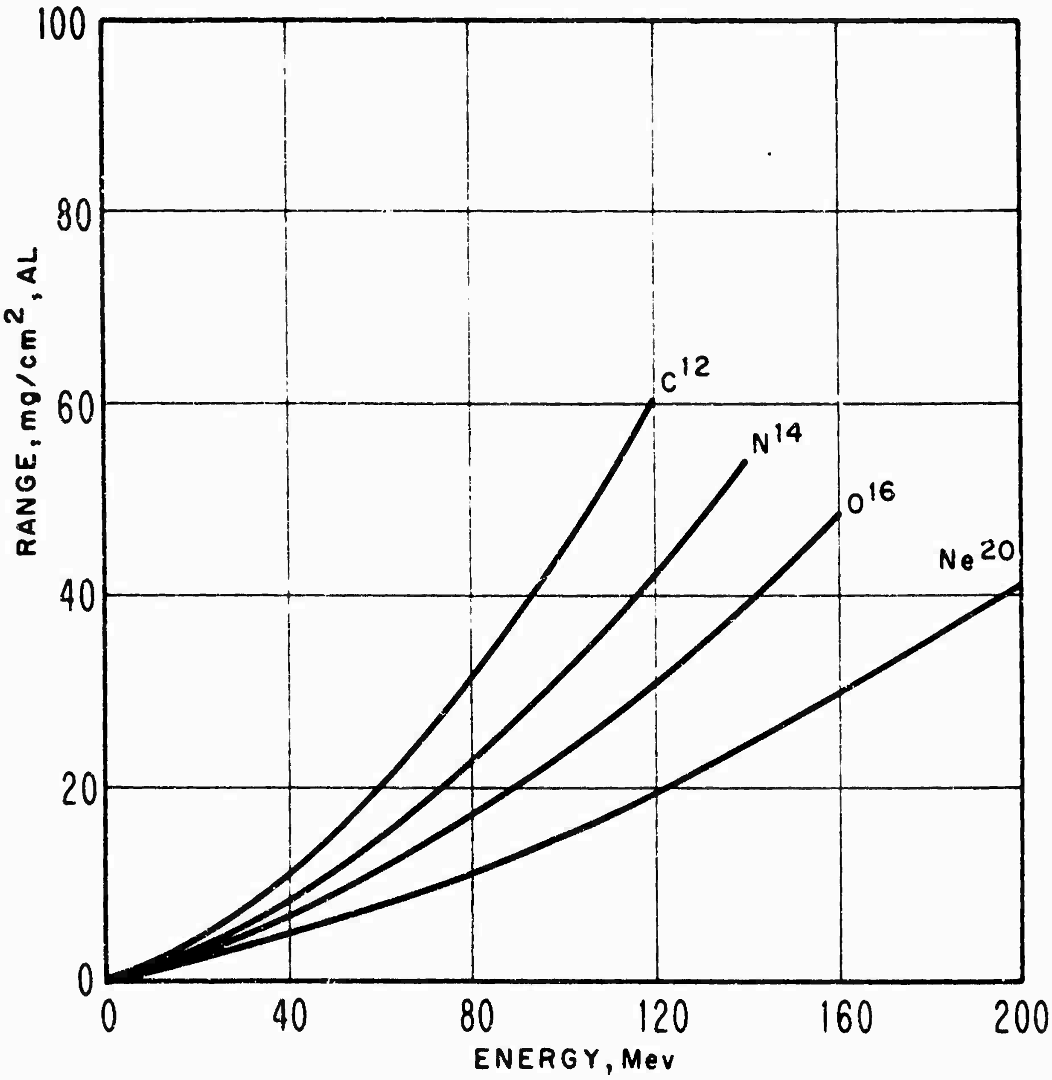


FIGURE 15. Ranges of ions in aluminum. Redrawn from Hubbard (1960).

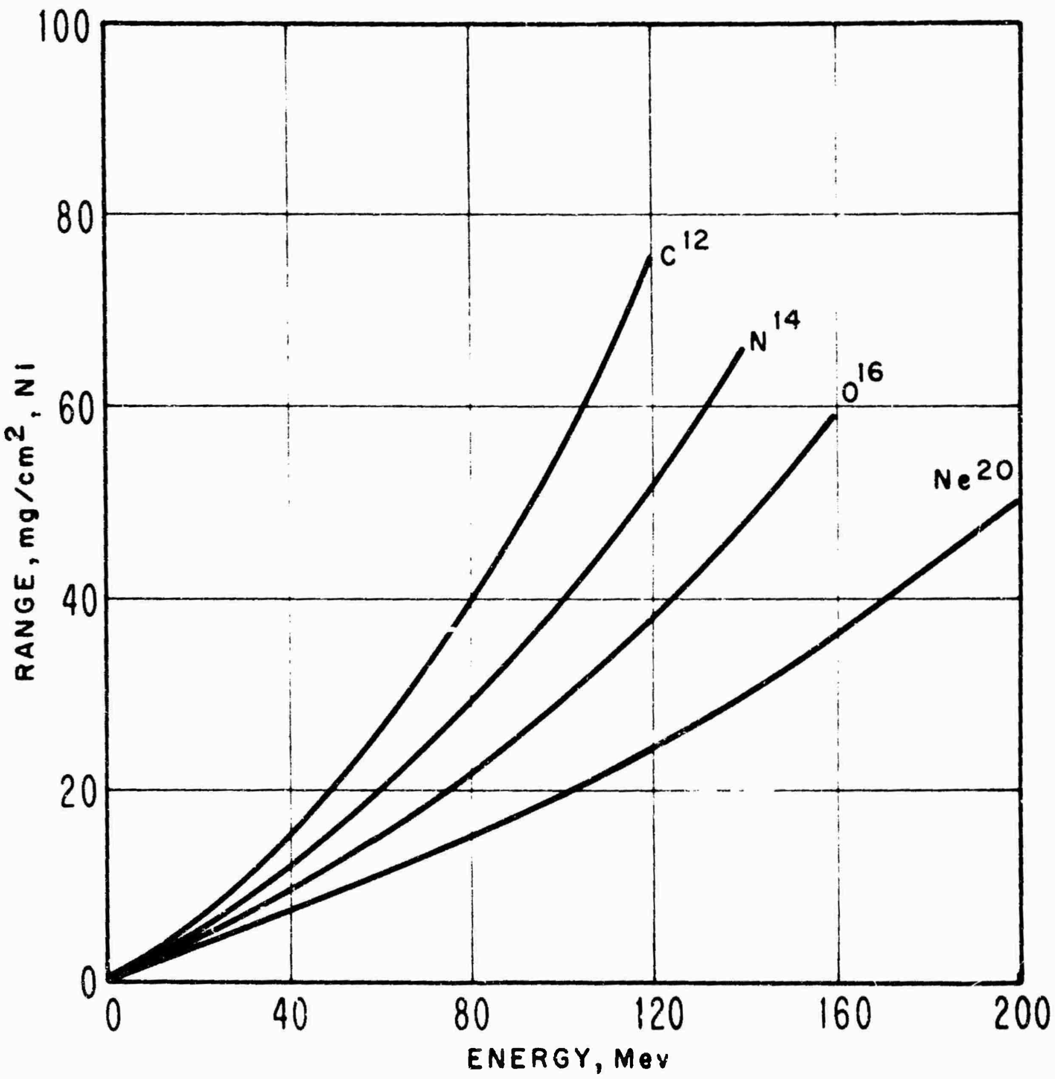


FIGURE 16. Ranges of ions in nickel. Redrawn from Hubbard (1960).

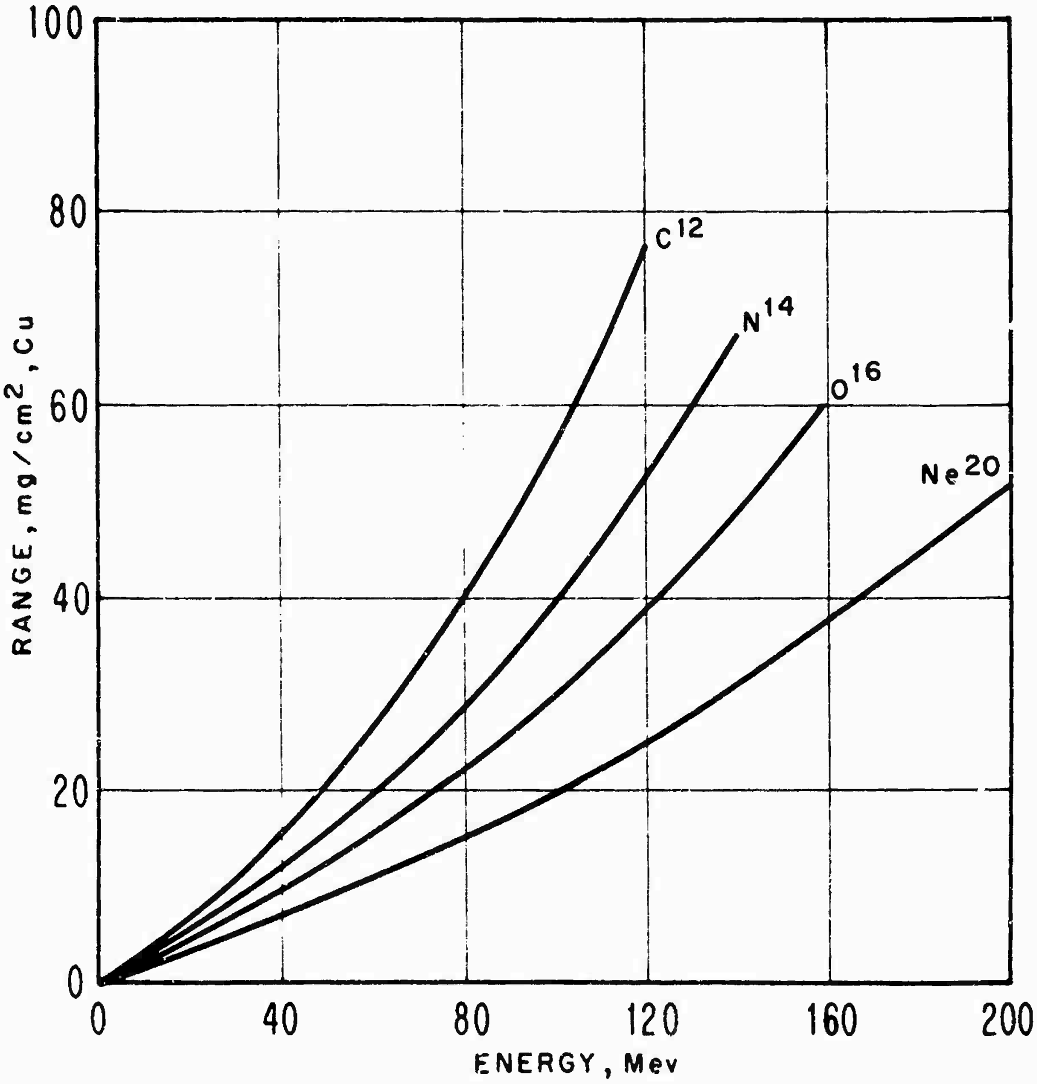


FIGURE 17. Ranges of ions in copper. Redrawn from Hubbard (1960).

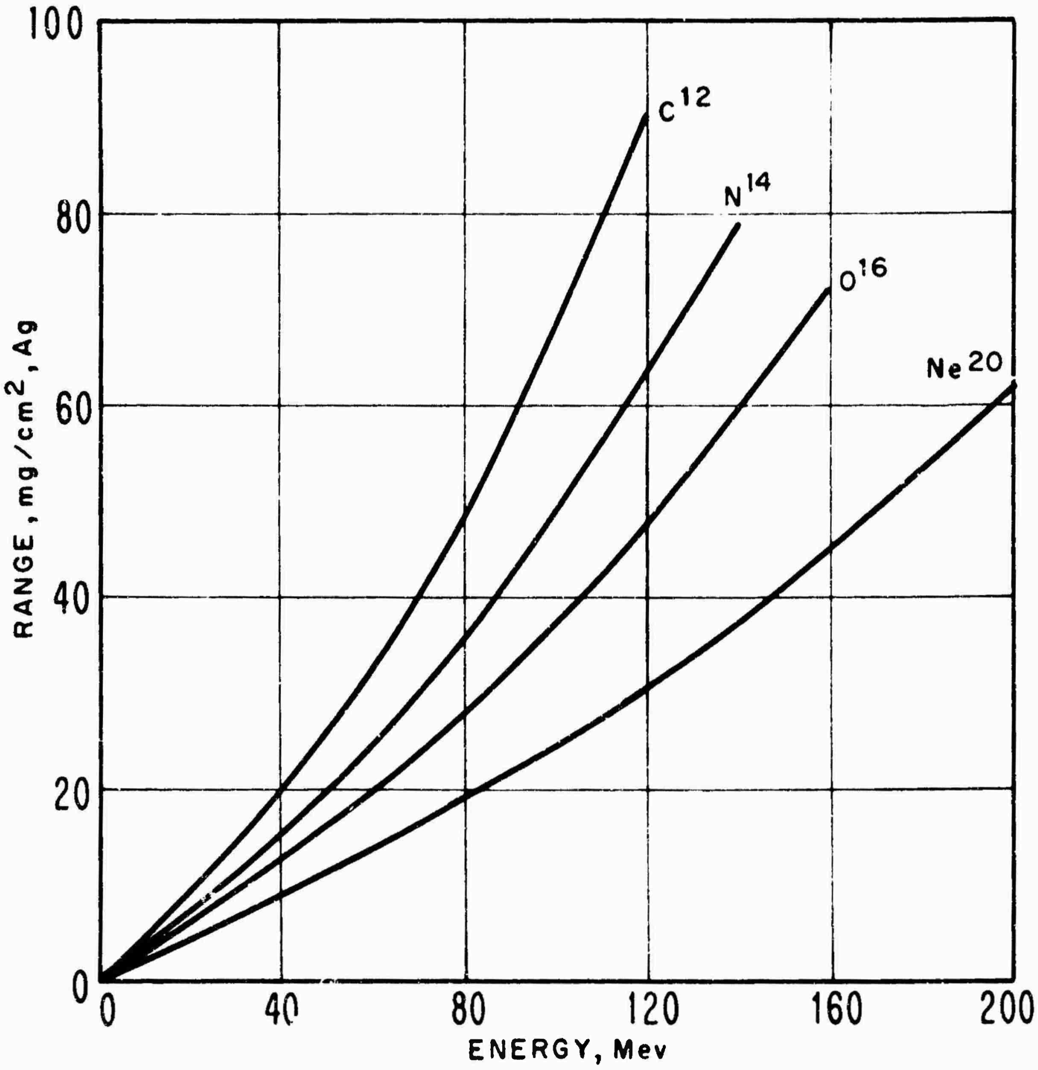


FIGURE 18. Ranges of ions in silver. Redrawn from Hubbard (1960).

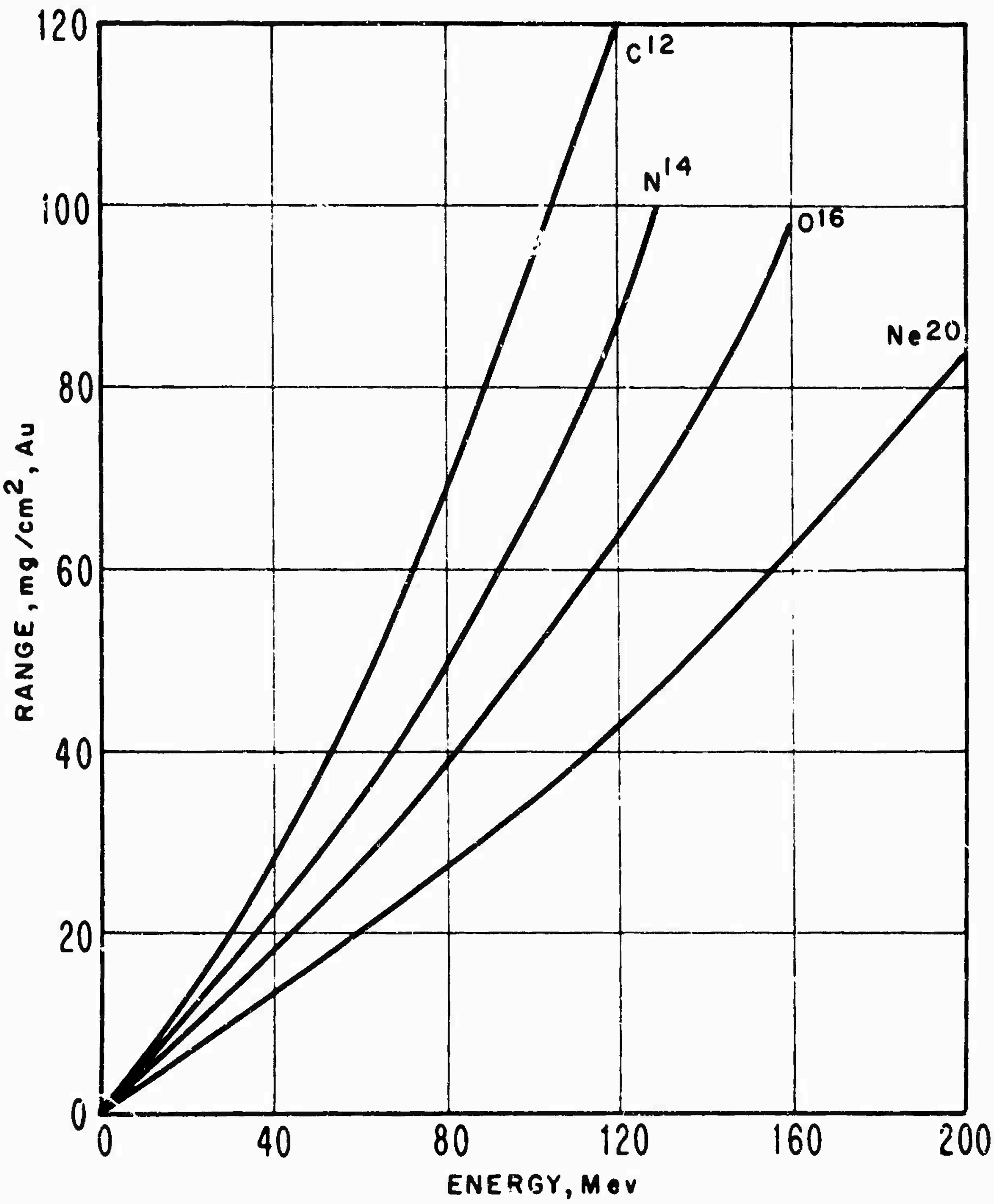


FIGURE 19. Ranges of ions in gold. Redrawn from Hubbard (1960).

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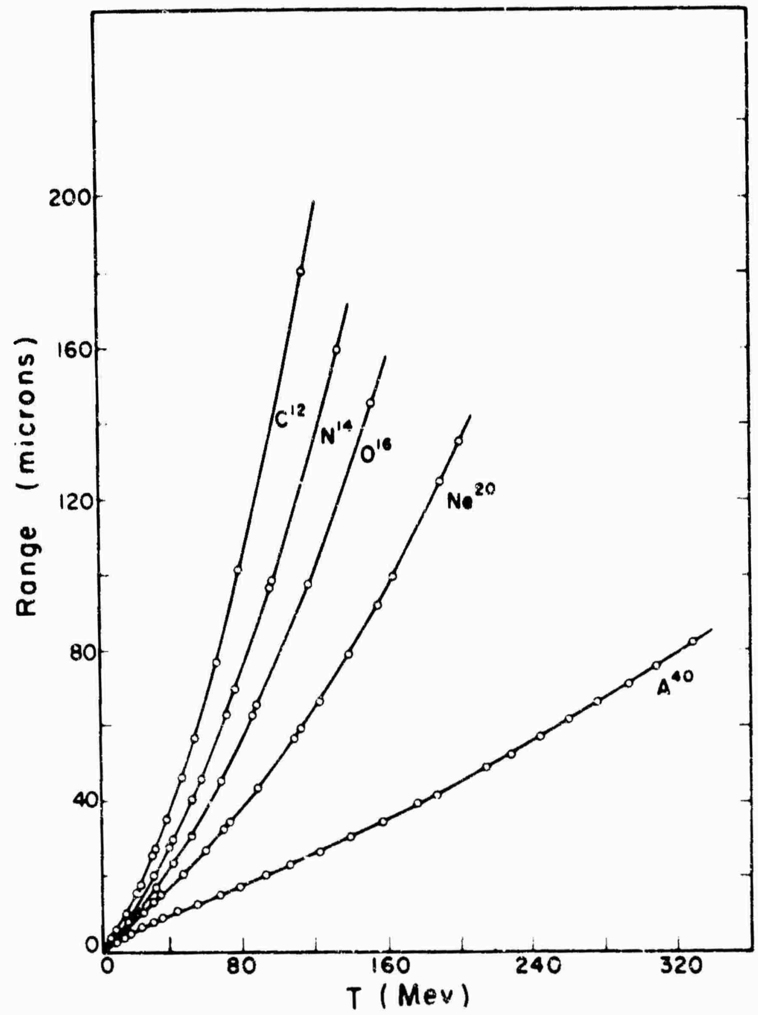


FIGURE 20. Range-energy relations for C, N, O, Ne, and A ions in Ilford emulsion ($3.815\ gm/cm^3$). The curves through the experimental points are the least-squares polynomials fitted to the data. From Heckman (1959).

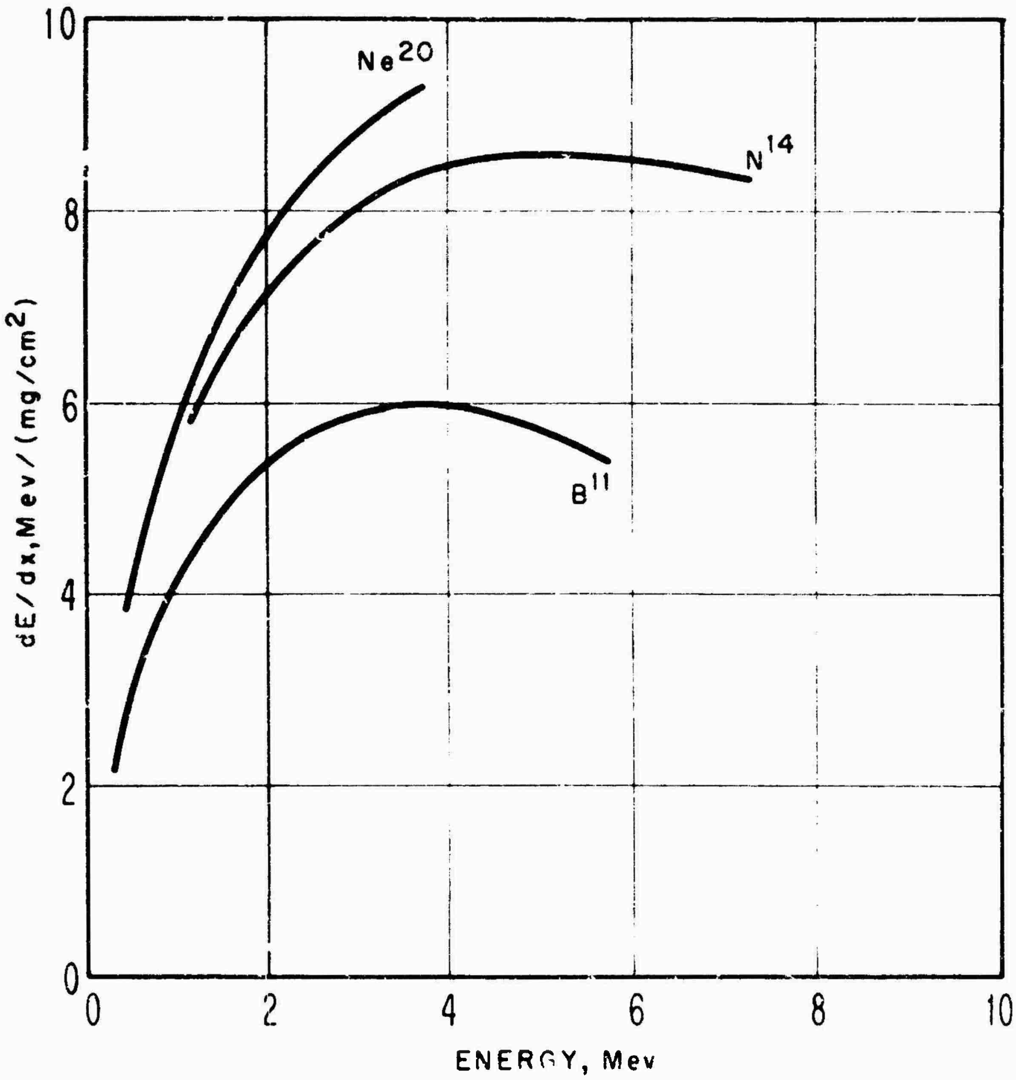


FIGURE 21. dE/ρdx for ions in air at 760 mm., 20° C. (ρ = 1.20 mg/cm$^3$). Redrawn from Teplova (1958).

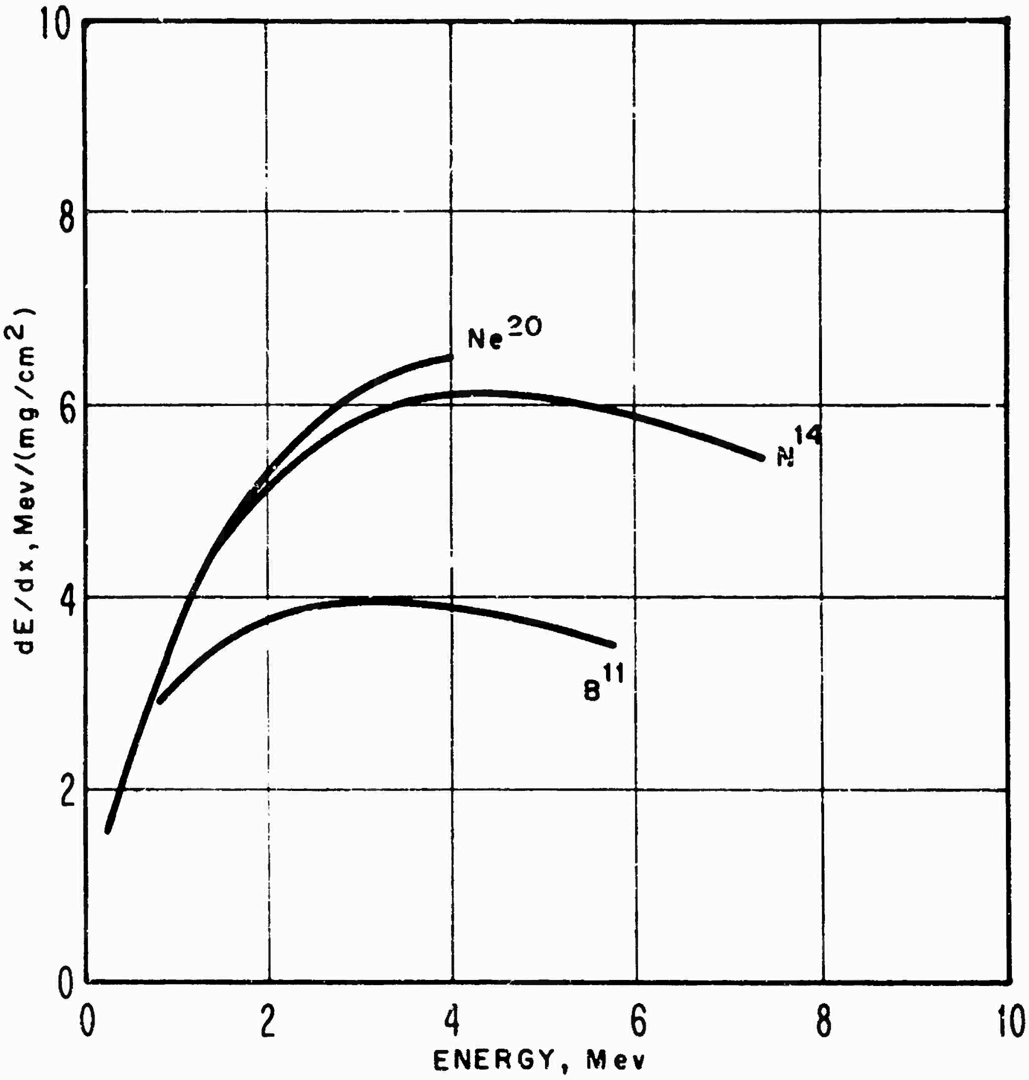


FIGURE 22. $dE/\rho dx$ for ions in argon at 760 mm., 20° C. ($\rho$ = 1.66 mg/cm$^3$). Redrawn from Teplova (1958).

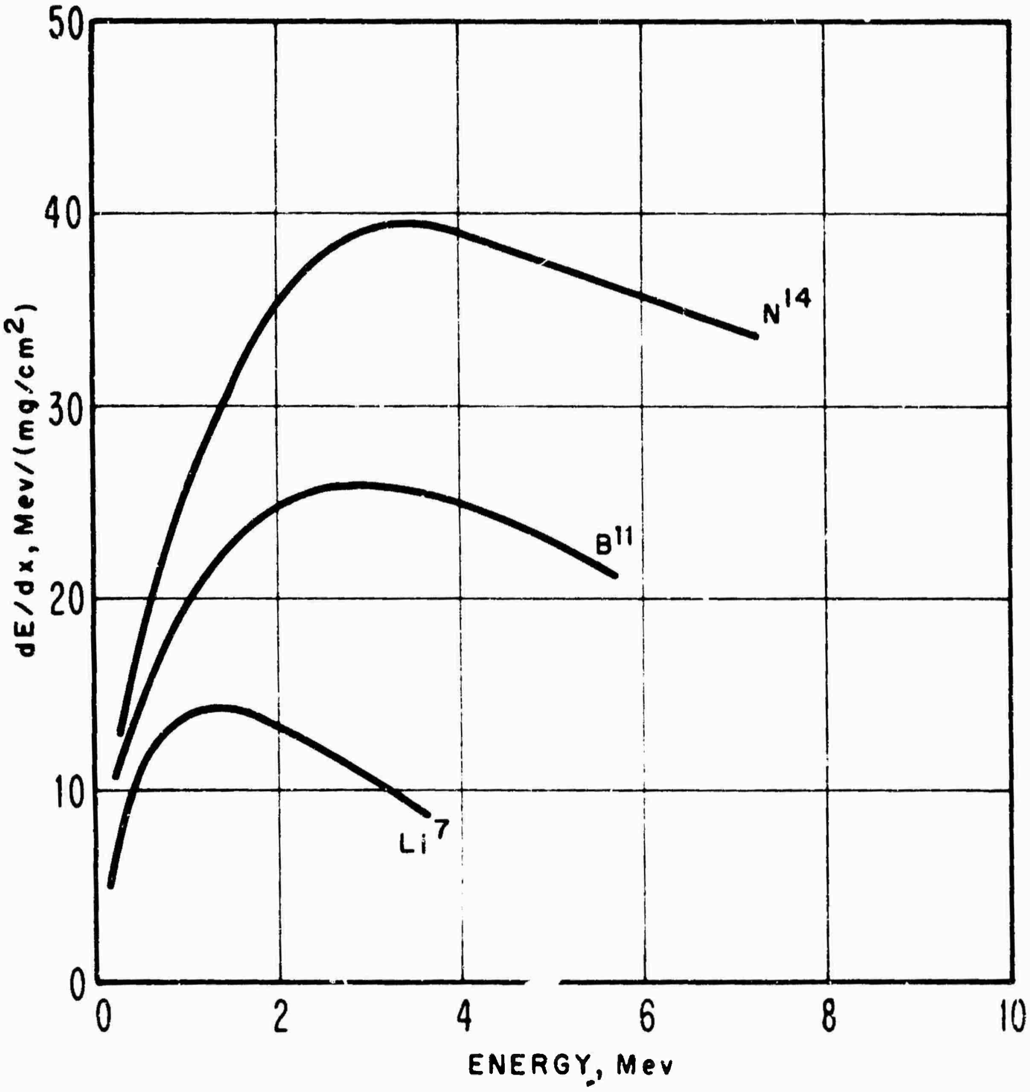


FIGURE 23. $dE/\rho dx$ for ions in hydrogen at 760 mm., $20^{\circ}$ C. ($\rho = 0.08$ mg/cm$^3$). Redrawn from Teplova (1958).

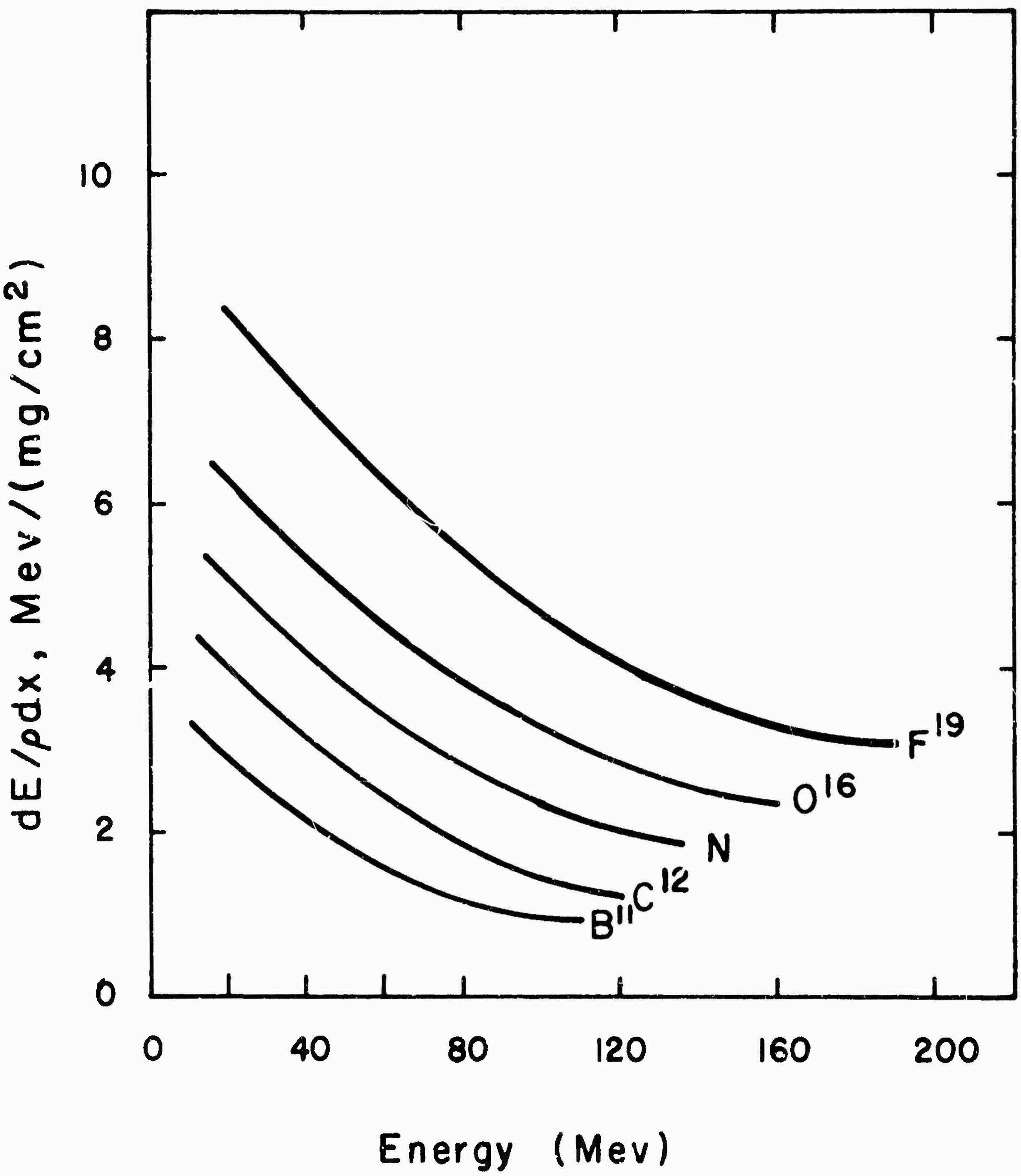


FIGURE 24. $dE/\rho dx$ for ions in hydrogen at 760 mm., 20° C. ($\rho$ = 0.08 mg/cm$^3$). Redrawn from Roll and Steigert (1959).

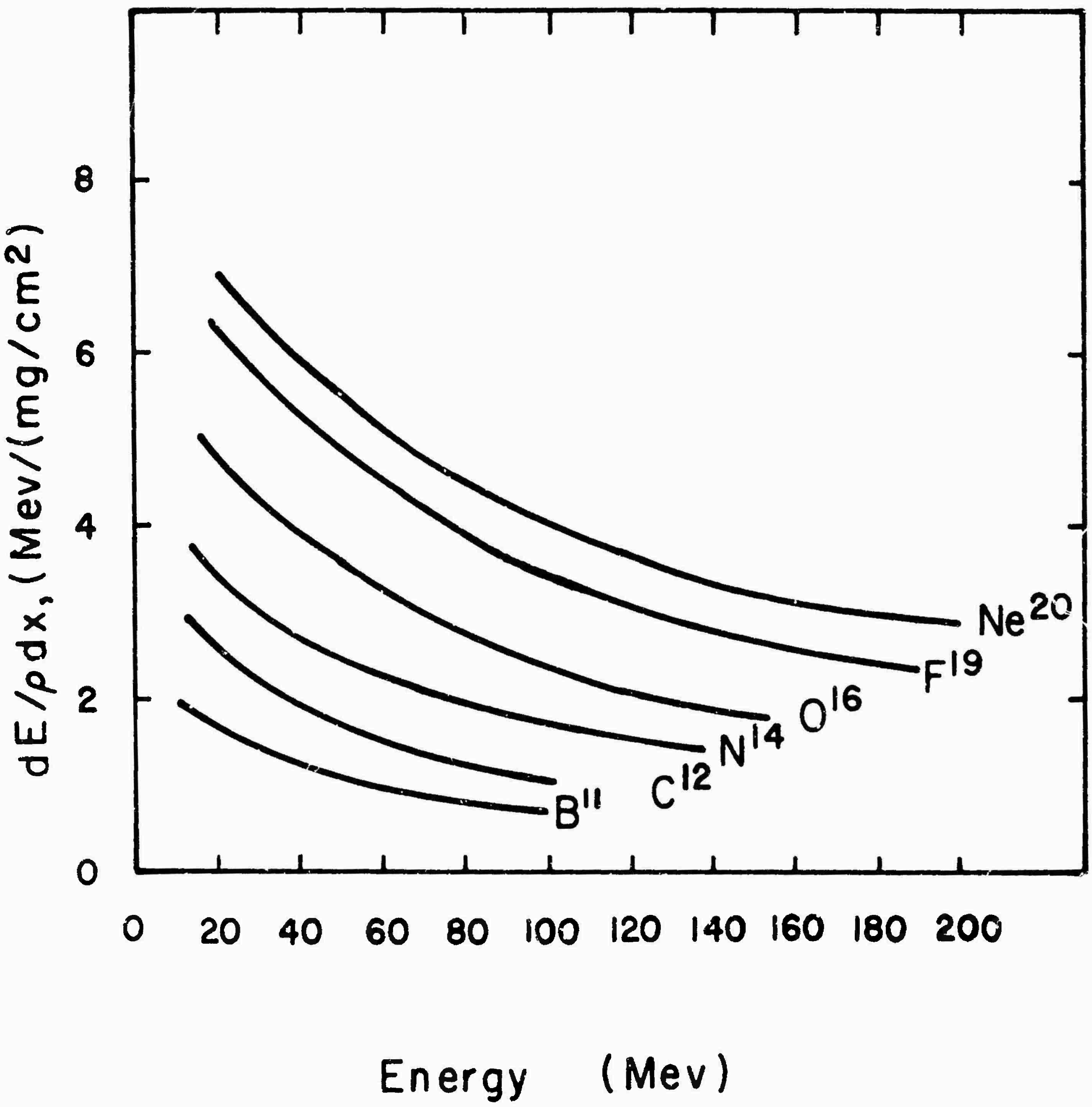


FIGURE 25. dE/ρdx for ions in nickel. Redrawn from Roll and Steigert (1959).

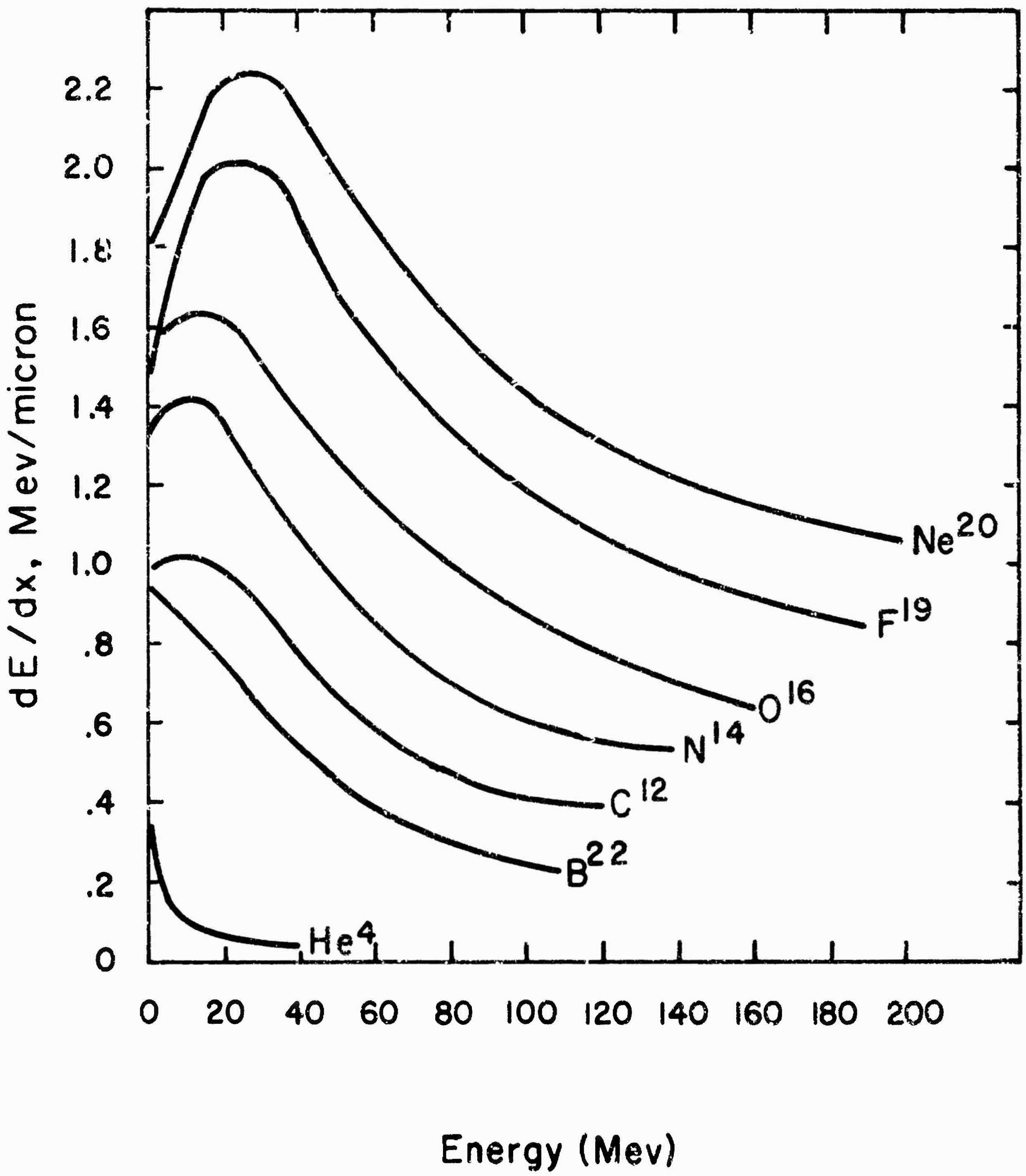


FIGURE 26. dE/dx for ions in emulsion. Redrawn from Roll and Steigert (1959).

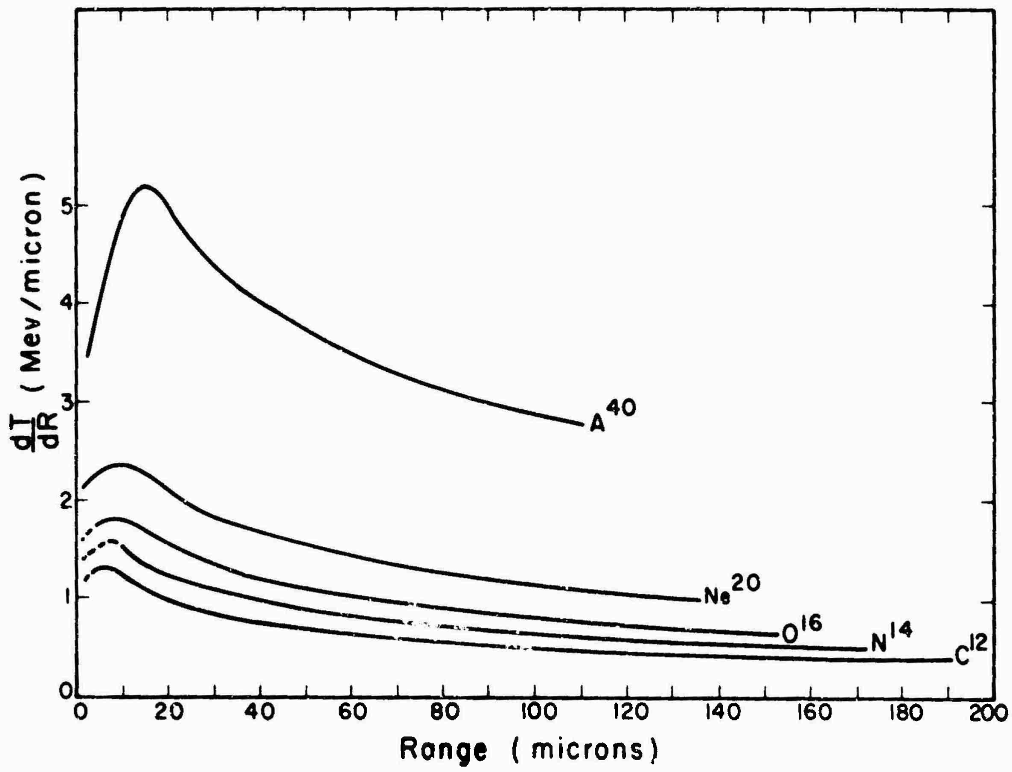


FIGURE 27. dE/dx in emulsion as a function of residual range. The dashed parts of the curves show extrapolations to shorter ranges than were actually measured. From Heckman (1959).

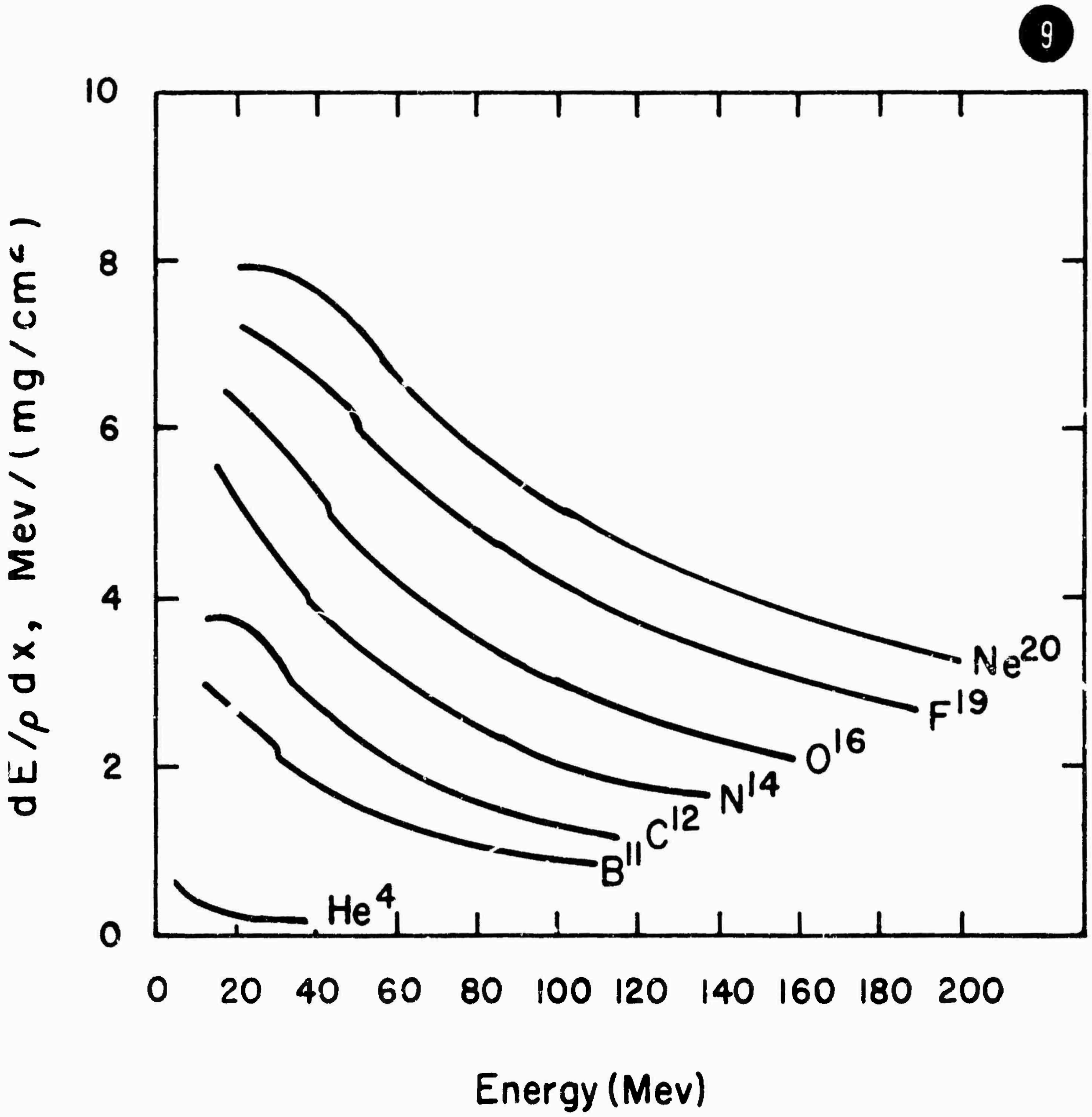


FIGURE 28. dE/ρdx for ions in aluminum. Redrawn from Northcliffe (1959).

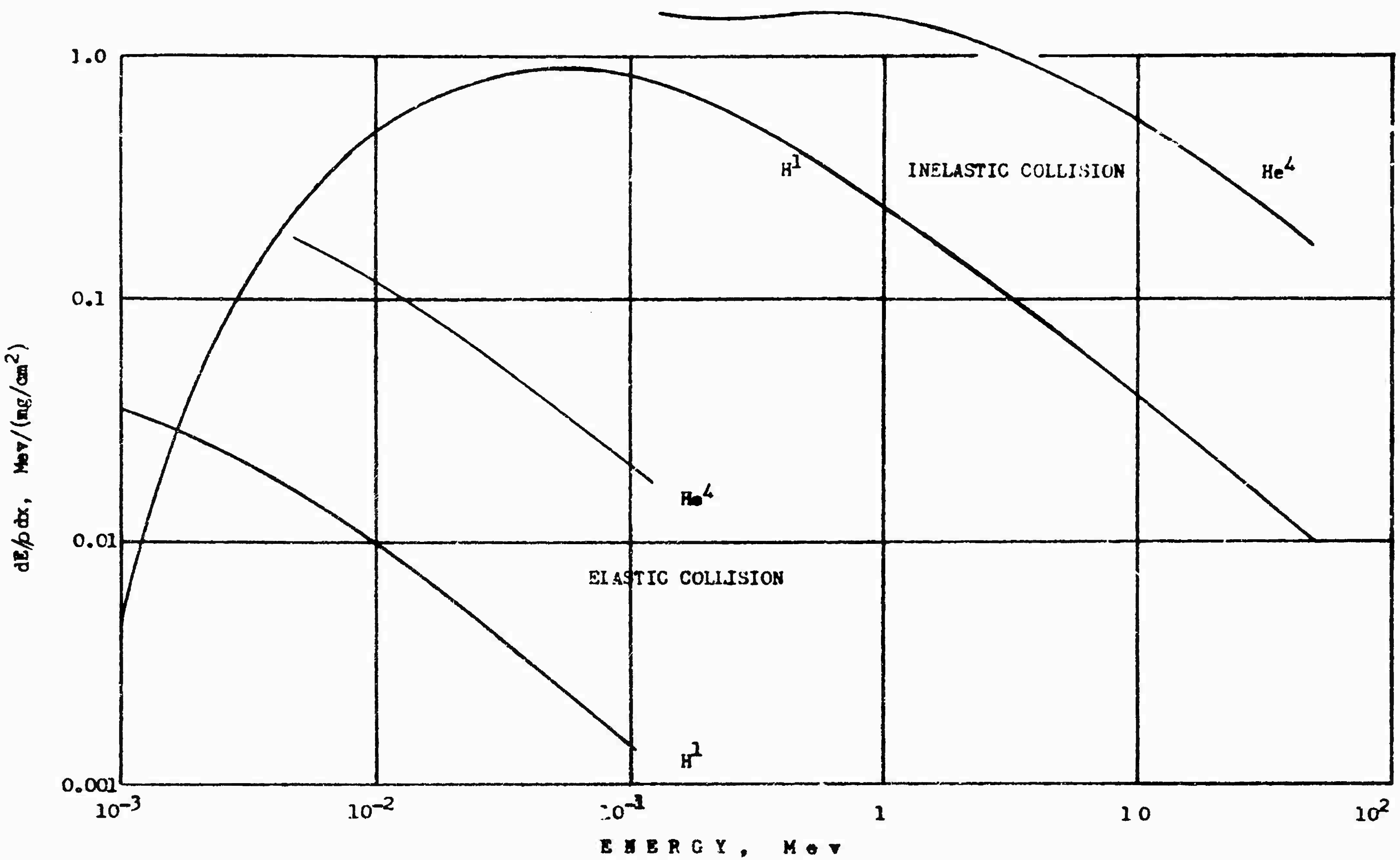


FIGURE 29. $dE/\rho dx$ for $H^1$ and $He^4$ ions in tissue. Redrawn from Neufeld and Snyder (1960).

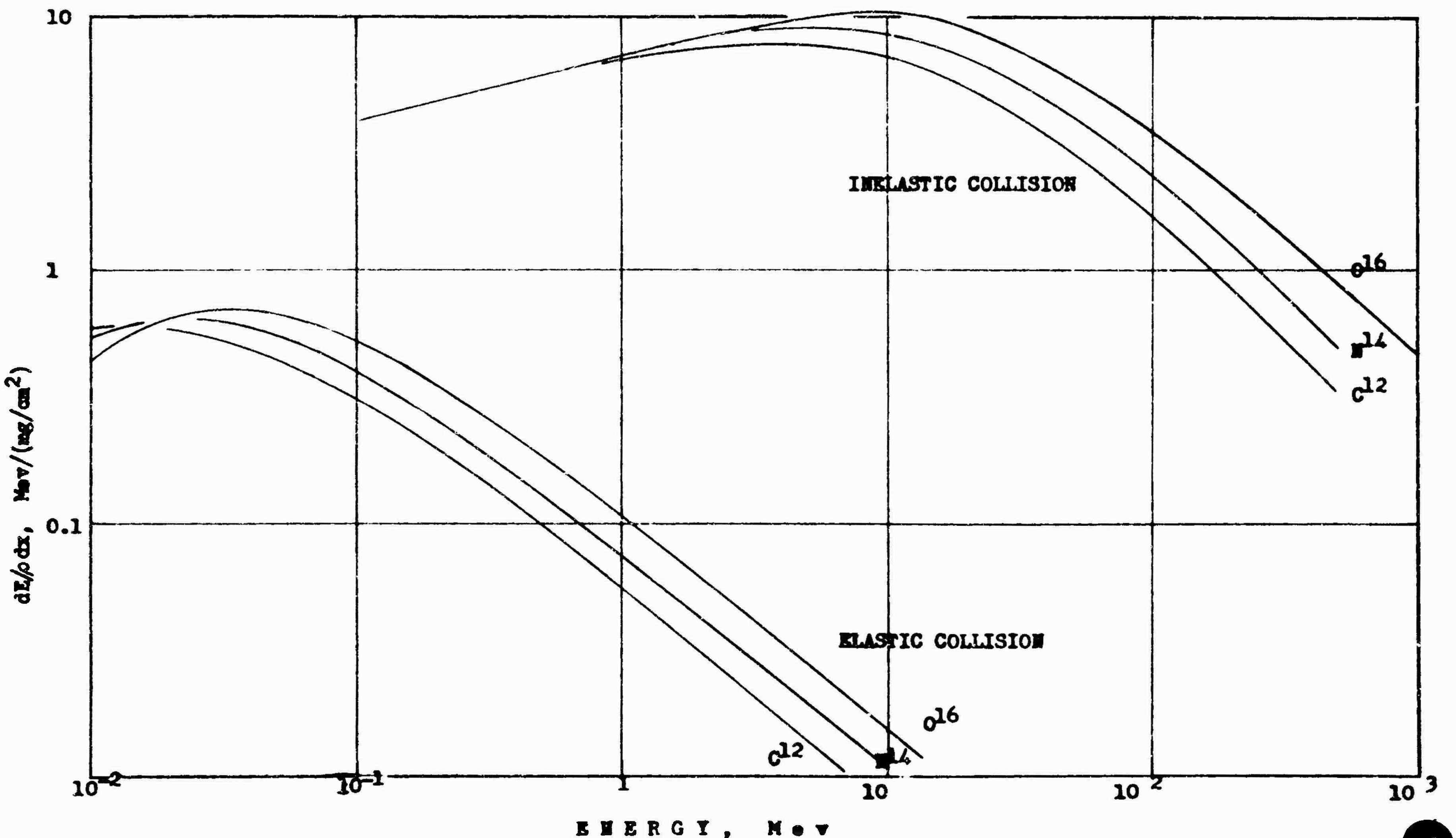


FIGURE 30. dE/ρdx for ions in tissue. Redrawn from Neufeld and Snyder (1960).

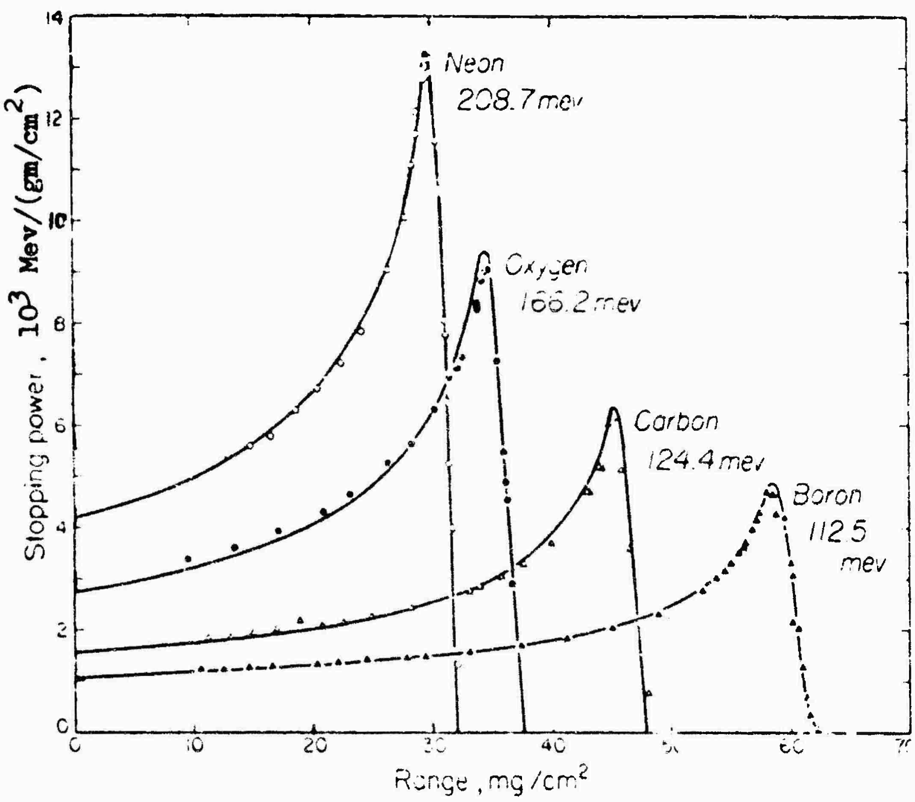


FIGURE 31. Bragg Curves of some heavy ions in tissue-equivalent material. Energy is 10.3 Mev/amu. From Brustad (1960).

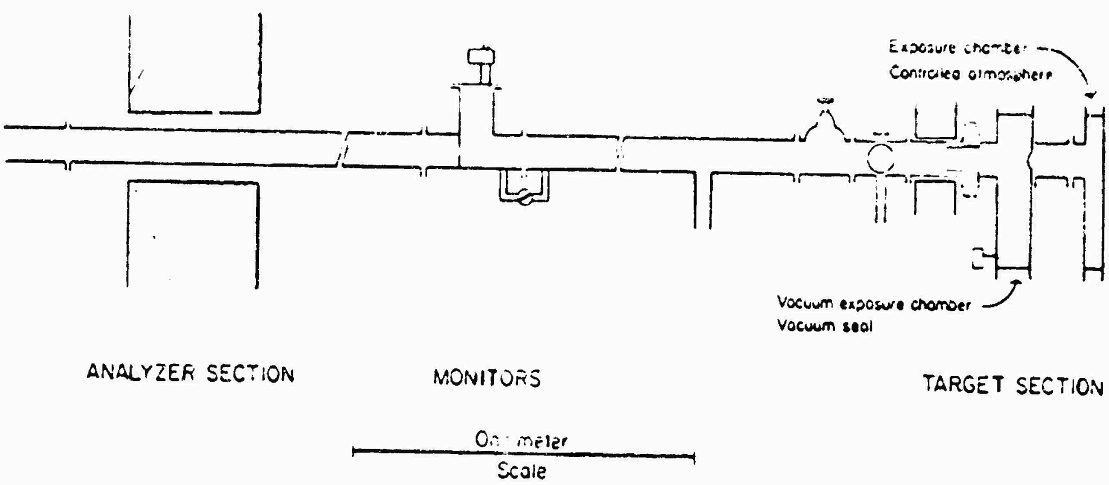


FIGURE 32. Schematic drawing of experimental set-up at the Berkeley Heavy Ion Linear Accelerator ("Hilac").

From Brustad (1960)

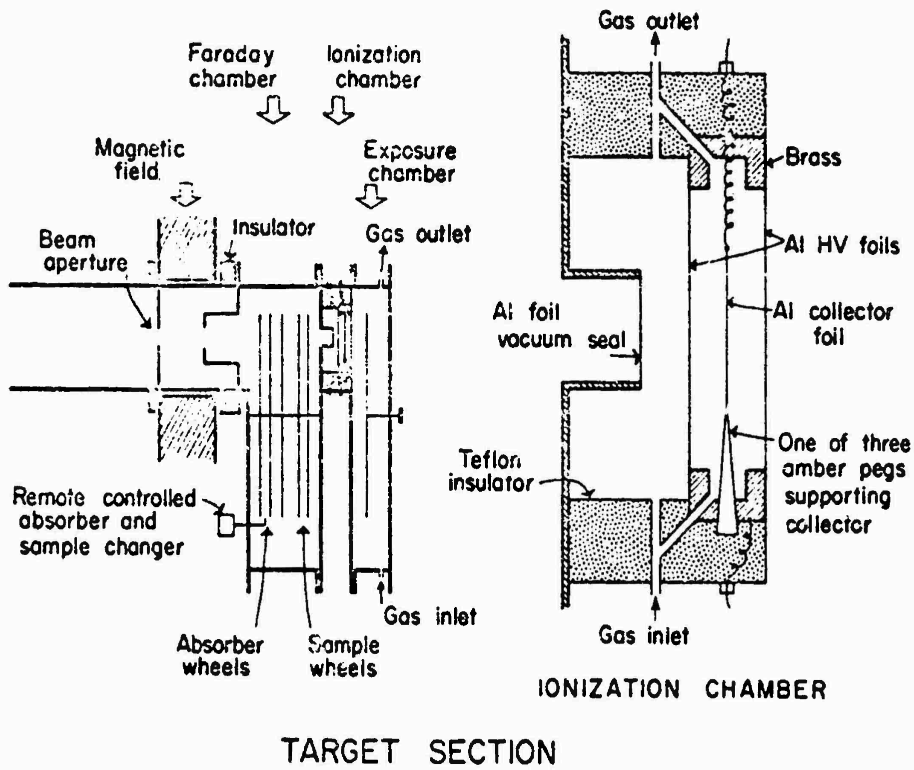


**FIGURE 33. Details of the bombardment chambers used for exposure of biological samples in vacuum and in controlled gaseous atmospheres. From Brustad (1960).**

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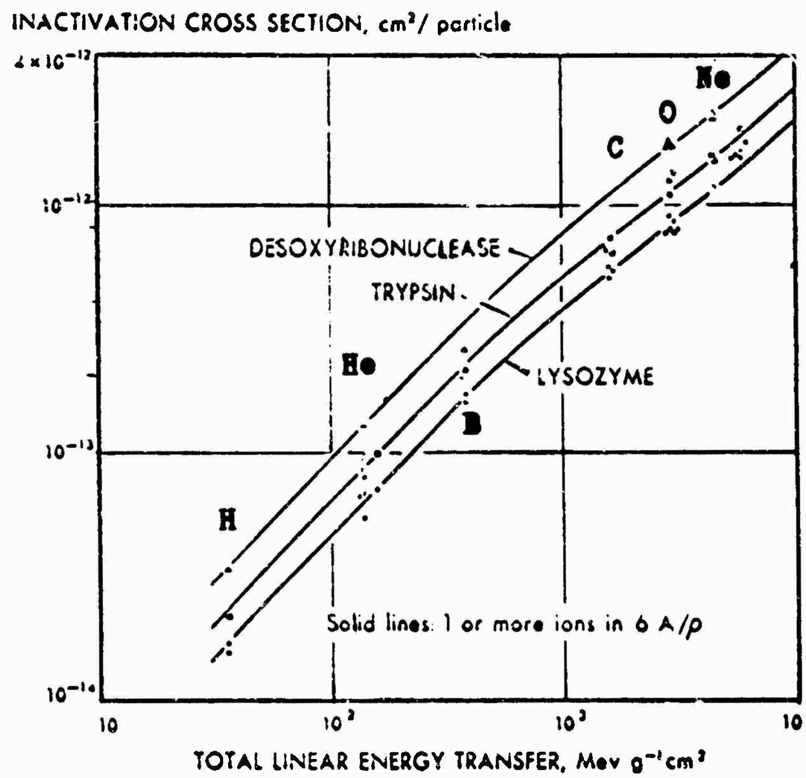


FIGURE 34. Inactivation cross section for lysozyme, trypsin, and desoxyribonuclease, determined from $n/n_0 = e^{-\sigma D}$, as a function of the total LET of the various particles used.

From Brustad (1960)

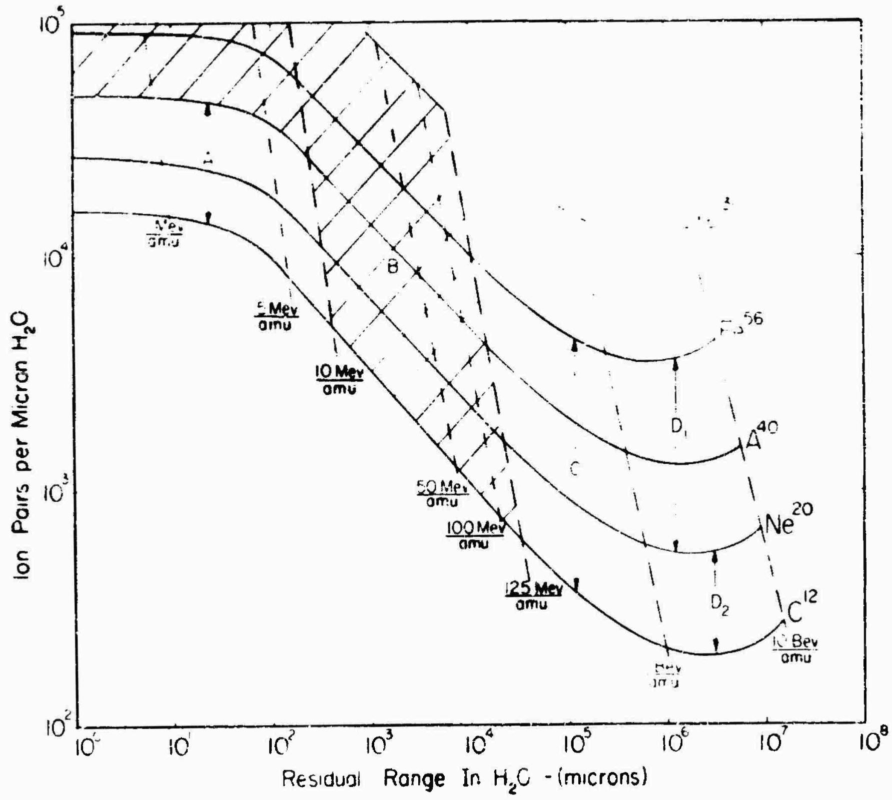


FIGURE 35. Specific ionization of heavy ions as a function of residual range in water. Adapted from Simons (1960).

REGIONS:

A: HILAC operating conditions (1 to 40 amu; up to 10 Mev/amu). Tracks have densely ionizing cores and limited radial delta rays, ending by thindown tracks.

B: Additional region included by projected future accelerators (1 to 131 amu; to about 125 Mev/amu).

C: Minimum energy of particles which can penetrate to the top of the atmosphere at middle latitudes varies within this region, from 125 Mev/amu, at sunspot minima, to 1 Bev/amu at sunspot maxima. Tracks have densely ionizing cores and extensive radial delta-ray patterns, and may have either thindown or collision endings. The smaller particles in this region have somewhat less densely ionized track cores than the heavier particles.

$D_1$: 1 to 10 Bev/amu; 20 to 56 amu. Tracks of particles in this region have densely ionizing cores and extensive radial delta-ray patterns, and end by collisions.

$D_2$: 1 to 10 Bev/amu; 12 to 20 amu. Tracks of particles in this region have extensive radial delta rays, less densely ionizing cores, and end by collisions.

TABLE I

| Z | Range of validity $E_t$ = Gev/nucleon | Integral spectrum in particles/cm² sec steradian | Limits of exponent |
|---|---|---|---|
| 1 | $2 < E_t < 20$ | $0.4 \; E_t^{-1.15}$ | 1.05 - 1.25 |
| 2 | $1.5 < E_t < 8$ | $0.046 \; E_t^{-1.6}$ | 1.3 - 1.7 |
| 3,4,5 | | ~50% of CNOF flux | |
| 6,7,8,9 | $3 < E_t < 8$ | $0.0024 \; E_t^{-1.6}$ | 1.45 - 1.75 |
| > 10 | $3 < E_t < 8$ | $0.0016 \; E_t^{-2.0}$ | 1.85 - 2.25 |

TABLE II

Charges of Fission Fragments Obtained by Bell and by Lassen

| Stopping Medium | Ion Species | Measurements of Lassen | Modified Values of Lassen | Values Calculated by Bell |
|---|---|---|---|---|
| Hydrogen | Light Fragment | 15.8 | 16.7 | 22.5 (21) |
| | Heavy Fragment | 12.6 | 13.3 | 16.3 (15) |
| Helium | Light Fragment | 14.1 | 14.9 | 16.5 |
| | Heavy Fragment | 11.6 | 12.2 | 12.5 |
| Oxygen | Light Fragment | 15.2 | $16.1 \pm 0.5$ | 15.5 |
| | Heavy Fragment | 14.1 | $14.8 \pm 0.5$ | 13.5 |

TABLE III

Comparison of experimental and theoretical cross sections for 8.7-Mev oxygen ions ($V/V_o$ = 4.7) in argon. From Gluckstern (1954)

$\sigma_{pq}/\pi a_o^2$

| $p \rightarrow q$ | Experimental[a,b] | Theoretical[c] |
|---|---|---|
| $3 \rightarrow 4$ | 2.27 ± 0.1 | 2.65 |
| $4 \rightarrow 5$ | 1.77 ± 0.15 | 1.75 |
| $5 \rightarrow 6$ | 0.81 ± 0.2 | 0.80 |
| $4 \rightarrow 3$ | 0.14 ± 0.1 | 0.65 |
| $5 \rightarrow 4$ | 0.57 ± 0.15 | 0.95 |
| $6 \rightarrow 5$ | 1.22 ± 0.2 | 1.30 |

a Determined from a least-squares fit to data in Fig. 10.

b Errors listed are estimated from the uncertainty in the data.

c Obtained from Fig. 3.

LECTURES IN AEROSPACE MEDICINE

# PROPULSION SYSTEMS

Presented by

Wernher von Braun

Director

George C. Marshall Space Flight Center

National Aeronautics and Space Administration

# PROPULSION SYSTEMS

by

Wernher von Braun

I would like to talk to you about vehicles for manned flight into space and here I would like to concentrate in particular on the Saturn vehicle, which in my opinion will develop into the workhorse for manned space exploration.

About two years ago, two men serving with the ARPA, Dr. David Young, now with Aerojet, and Mr. Richard Canright, now Project Engineer for Saturn at NASA Headquarters, came to Huntsville and asked us if we thought we could strap eight existing IRBM rocket engines into one bundle, fire it up and make a big booster. We said we could try.

From these humble beginnings, the Saturn program began.

I do not believe that Saturn is just a stop-gap solution. It has been presented as such occasionally. There may be one reason for this. Saturn is a determined attempt to utilize existing technology to get a bigger space cargo carrying capability. We have refrained from using any fancy improvements in the Saturn system - from following any new and unproven ideas. We just want to combine what we have today. Some people have said the fact that we package eight engines in the tail of a rocket to get the necessary rocket thrust is an admission that this is a stop-gap solution, but I would like to point out that a B-52 also has eight engines.

Figure No. 1

The first slide shows an artist's concept of what the Saturn C-1 will look like on its launch pad at Cape Canaveral. You see to your right a vehicle 180 feet high, consisting of three stages. The first stage is powered by eight kerosene-liquid oxygen engines. The second and third stages are liquid hydrogen-liquid oxygen powered. The second stage has four engines and the third stage has two engines. Atop the third stage rides the payload. The entire Saturn rocket takes off from this launcher. It is a zero-length launcher, which means when Saturn is one inch in the air it is completely free of ground central. Prior to take-off Saturn is serviced from this structure. The various platforms here provide access to various stations in the rocket. This structure is withdrawn prior to launch, and parked in a position about 300 feet from the launching pad. There is also a tower on this side, which we call the umbilical tower because it carries cables into the various rocket stages and up here to the payload. The umbilical tower also has a crane which can be used to exchange parts in the rocket.

Figure No. 2

The next slide deals with two phases of our Saturn development. Our first objective is the so-called Saturn C-1, which you see here to your left. You see the eight engine kerosene-oxygen booster, the second hydrogen-oxygen stage, the third hydrogen-oxygen stage, and finally the

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payload compartment. This C-1 Saturn has an orbiting paylcad capability of approximately 19,000 pounds. That is net payload not including the top stage. As phase number two of the Saturn program we plan to build the Saturn C-2. The C-2 has the same booster, but the second stage of the C-1 has been moved one notch up and has become the third stage. In lieu of the second stage we have inserted a brand new stage which is powered by four liquid hydrogen-liquid oxygen rocket motors that are about 10 times as powerful as the motors used in the C-1's second stage. As a result, a much greater portion of the total weight of the C-2 rocket is in the high energy liquid hydrogen-liquid oxygen class and thus we obtain a much greater payload capability: 45,000 pounds in a low orbit compared to nineteen thousand with the C-1.

We propose to fire the first operational three stage C-1 in the Summer of 1964. Flight testing of the Saturn C-1 will be carried out gradually. We will first make single stage flights only, with all the upper stages being dummies. Then we will fire a live first stage and a live second stage with only the third stage being a dummy. Finally we will follow up with complete three stage flights by the end of 1963. In the summer of 1964, C-1 will be operational, which means it will be ready to carry useful payloads. C-2 will trail C-1 development by about two years and we can expect this vehicle to be operational in 1966.

Figure No. 3

Next slide shows Saturn's first stage. You see the cluster of tanks in which the propellants are carried. There is a total of nine tanks, one central one of 105 inches in diameter and eight outer ones of 70 inches in diameter which surround the central tank. The inner tank and four of the outer carry liquid oxygen whereas only the remaining four outer tanks carry kerosene. Tanks containing the same propellant are interconnected. Down here are the eight rocket engines. The four centrally mounted engines just provide thrust. The four outer ones are swivel-mounted and can be deflected by hydraulic actuators. In addition to thrust, these outer engines provide the control forces for the entire Saturn vehicle during first stage powered flight. The first stage burns one hundred and twenty five seconds. The insert shows how the first stage fits into the Saturn C-1 and the Saturn C-2 configuations.

Figure No. 4

Here is the first stage in our shops at the George C. Marshall Space Flight Center in Huntsville. You see the cluster of tanks being assembled. Located in the tail of the first stage are the eight H-1 engines. Each engine gives 188,000 pounds of thrust.

Figure No. 5

Here you see one such engine close up.

Each engine has its own turbo pump which feeds the liquid oxygen

and the kerosene under high pressure into the combustion chamber. Each of these turbopumps has 5,500 horsepower. The turbines are driven with bulk fuel which means there is a little gas generator burning kerosene and liquid oxygen which provides a high pressure gas of moderate temperature. The turbine exhaust exits through an exhaust stack into a so-called exhaustarator where the slow moving turbine gas exhaust is admitted to and carried away by the supersonic jet. Prior to combustion, the kerosene is used to cool the combustion chamber and the nozzle. It flows through these tubes up to this point. There the flow is reversed and the kerosene finally flows into the injector plate. Every drop of kerosene goes to the cooling jacket prior to being injected into the combustion chamber. It is like an automobile engine that is cooled by running the gasoline through the cooling jacket prior to admitting it to the carburetor. Up here is a swivel point about which the engine may be deflected plus-minus 10° for control purposes. The thrust of 188,000 pounds of this engine is equivalent to approximately 4 million horsepower. Since Saturn's first stage has eight of these engines, the Saturn first stage has a total performance rating of about 32 million horsepower.

Figure No. 6

Here is a radical new concept that we are presently exploring to recover this first stage. This contraption looks like it was invented by Leonardo da Vinci but it is actually a very attractive recovery scheme presently under investigation at NASA's Langley Research Center.

Essentially, it is a parachute that takes the form of a glider. Prior to deployment it is strapped to the booster and packed tightly like a parachute. It is made of cloth and when stowed hardly protrudes from the groove between two adjacent booster tanks. During a typical Saturn flight the booster reaches approximately Mach 3, flying at an angle of $60^{\circ}$ upwards. It then coasts through a short ballistic trajectory and enters the atmosphere again. This tail skirt stabilizes the booster while it decelerates down to about sonic speed by sheer drag. Now this paraglider is deployed and assumes its shape. By pulling in these shroud lines you can bank the gliding vehicle and by playing out or pulling in the front line up here you can change the angle of attack. Thus the vehicle even has a flare-out capability, which means you can bring it down on a runway and land it with automatic guidance like a drone plane. Touch down speed is approximately 60 knots. Much research and development has gone into this idea. Several corporations, among others, Ryan and North American Aviation, have contracts in this field. You might be interested in knowing that the Ryan Aeronautical Company in San Diego proposes to fly a little airplane of about 100 horsepower with just such a wing next month.

Figure No. 7

The next slide shows a modified concept of this paraglider. Rather than having one large glider, this one consists of three small ones.

The advantage of this scheme is that you can release the uppermost glider first and have it pull out the other glider surfaces one after another. In this way one can adapt the deployment of the glide surfaces a little better to the gradual speed loss of the vehicle.

We have analyzed this paraglider recovery scheme very carefully. It actually appears possible to fire Saturn from Cape Canaveral and with this method the booster on the Canaveral skid strip 20 minutes later. I would like to point out, however, that success or failure of this recovery method is by no means a crucial factor in the Saturn program.

Figure No. 8

This is the second stage of the Saturn C-1. For reference purposes again, in the C-1 it is the second stage; in the C-2 it will become the third stage. This stage is liquid hydrogen-liquid oxygen powered and uses four Pratt and Whitney engines of 17,500 pounds of thrust each, so the total thrust of this stage is 70,000 pounds.

Let me elaborate a little more on this engine, because here we are really talking about brand new technology.

Figure No. 9

Here it is. This engine has a turbo pump to pump the liquid hydrogen and the liquid oxygen in the combustion chamber. The liquid hydrogen is first used to cool the nozzle. Only then will it burn in the liquid oxygen which flows into the injector plate direct. But in

this particular rocket engine, we use the cooling heat provided by the combustion chamber to drive the turbine. This is a new approach and radically different from Rocketdyne's gas generator chamber. Remember, in this Pratt & Whitney engine we do not burn the liquid hydrogen with liquid oxygen, we just heat the liquid hydrogen in the cooling jacket. Now since liquid hydrogen is so very cold, you can even start this rocket engine without a primer. All you have to do is open the valves and let the liquid hydrogen flow into the warm cooling jackets. It will evaporate very violently and whip up the turbine speed. As the pump builds up more pressure, it will feed more hydrogen through the cooling jackets so it really bootstraps itself. It sounds fantastic but it works beautifully and very reproducible, too. Development of this engine was initiated in about 2½ years in connection with the Centaur program. It has many hundred successful tests on record and holds all the promise of becoming a fine rocket engine.

Figure No. 10

Here are two of these engines in the assembly facility of Pratt & Whitney, West Palm Beach, Florida.

Figure No. 11

Here is how this engine is tested. The second Saturn stage operates only in outer space. Since the atmosphere surrounds any ground test stand, we have to create an artificial vacuum in order to operate this rocket

10

motor under its proper outer space conditions. This is done as follows. We have a long tube here into which the rocket engine exhaust discharges.

Figure No. 12

These two tubes for two engines are evacuated by means of a steam ejector, which is essentially a steam-driven vacuum pump. At first, each tube is closed by a lid at the end. Prior to the test, the steam ejector evacuates the tubes. As you start the rocket engines, the lids fly open and from that moment on each rocket motor creates its own vacuum working like a jet pump. We call these tubes conversion-diversion diffusers.

Figure No. 14A

Here is the complete second stage of the Saturn C-1 with the four engines. What you see here is a model. This stage is under development at the Douglas Aircraft Co., at Santa Monica, California under contract with the George C. Marshall Space Flight Center.

The liquid-hydrogen tank is up here, the liquid-oxygen tank is down here and here you see the engines. All four engines are swivel-mounted. The entire stage rides on top of the big clustered booster stage which we are developing in Huntsville.

Figure No. 15

This is a full scale mock-up of the tail end of the second stage at the Douglas plant. What you see here is the liquid-oxygen tank; this

is the thrust mount; and here are mock-ups of the four engines which Douglas receives as government-furnished equipment from Pratt and Whitney.

Figure No. 16

The forward portion of the second stage, again in the Douglas plant.

Figure No. 17

Here is the third stage of the Saturn C-1 which might also be used as a fourth stage in the C-2 for high speed missions. This vehicle is an outgrowth of the so-called Centaur rocket which will first be tested with an Atlas ICBM as first stage. For this reason, the development of this vehicle is already a little further ahead than the previous stage. Therefore I can show you a few slides of actual hardware.

Figure No. 18

Here you see the Saturn C-1 third stage in the Astronautics Plant of Convair in San Diego. Here is a tank and here are the two engines. Here are the turbopumps. The stage has a diameter of ten feet.

Figure No. 19

The same Saturn C-1 third stage, is shown here on the Convair test stand in Sycamore Canyon, about 15 miles east of San Diego. You see the tankage here; here you can clearly recognize the two engines, and here you see the upper ends of these conversion-diversion diffusers which permit operation of the engines in vacuum expansion conditions just like in outer space.

Figure No. 20

The next slide deals with that new second stage of the Saturn C-2 which we will need in order to more than double our payload capability. This again will be a liquid hydrogen-liquid oxygen stage.

Figure No. 21

The rocket engine you see mocked-up here is called the J-2 engine. It is under development at Rocketdyne, a division of North American Aviation, and it burns liquid hydrogen-liquid oxygen just like the much smaller Pratt & Whitney engines. But the J-2 will have 200,000 pounds thrust per barrel, which means it is more than 10 times as powerful as the little Pratt & Whitney engine. But its design is based on essentially the same technology. Liquid-hydrogen and liquid-oxygen pumps will be separate and each will have its own turbine.

Rocket engines have longer lead times than air frames in the missile business. It is for this reason that no air frame contract for the second stage of Saturn C-2 has been let yet.

Figure No. 23

The next slide deals with a variety of tasks for Saturn. Capable of virtually unlimited growth and versatility, the Saturn can: land--softly--a truckload of scientific instruments on the moon, Mars or Venus; assemble various spacecraft in orbit around the earth; or put up orbital tankers to refuel these assembled spacecraft so they can

proceed on long voyages to the moon or planets. Even <u>without</u> orbital refueling, Saturn can send three men around the moon and back; <u>with</u> orbital refueling, it can land three men on the moon and return them to earth.

Now I should like to digress for a moment to tell you something about an exciting new study that we are making to join two space vehicles together....while in earth orbit....by using existing vehicles and technology.

The joining of two objects in space to become a single unit has never been attempted.

We have awarded a $100,000 contract to Lockheed Aircraft Corporation to study this possibility. The Space Technology Laboratories will assist in the study. The actual vehicle under consideration for this purpose is Atlas-Agena B. By joining space objects together with these rockets we hope to obtain information that will help us when the much larger and more powerful Saturn is used to assemble or refuel spacecraft in orbit.

<u>Figure No. 29</u>

In this picture you see the first stage of the Saturn in our big static test stand at Huntsville. You see the tank cluster here with the engines. Over here is a large service crane.

<u>Figure No. 30</u>

Here you see a static firing of the Saturn first stage as seen from a helicopter.

Figure No. 31

This is the same scene from a little closer up. You see all eight engines going full blast. This cloud is the result of little argument between the rocket fire and water, for we inject 45,000 gallons of water a minute into the jet to cool our jet deflector.

Figure No. 32 and 32a

This is the barge which we are going to use to carry the Saturn booster from Huntsville to Cape Canaveral. Although the Saturn first stage will charge along at supersonic speed when launched, it travels not faster than 6 knots on its long journey from Huntsville down the Tennessee River, the Ohio and the Mississippi and around the tip of Florida to Cape Canaveral.

Figure No. 33

You will remember that the very first picture I showed you was an artist's conception of the Cape Canaveral service structure for Saturn. Now what you see here is an actual photograph of it. You see the service structure, which is 310 feet tall, the highest building in the State of Florida. The steel construction is completed, but some of the servicing platforms are still missing and, of course, elevators and air conditioning equipment have not been installed yet. This whole contraption travels on rails between a parking position and the launch table from which the Saturn will be launched.

**Figure No. 35**

In this aerial view, you see again the service structure and the launch table. The umbilical tower is missing, but over here you see the blockhouse. This is where the ground crew will be during the launching of Saturn. This long tube-like structure is a cable tunnel connecting the launch platform with the blockhouse. There are a few additional support facilities surrounding this area. The whole complex is a \$34 million installation. Two more similar launching sites for Saturn have been approved for construction.

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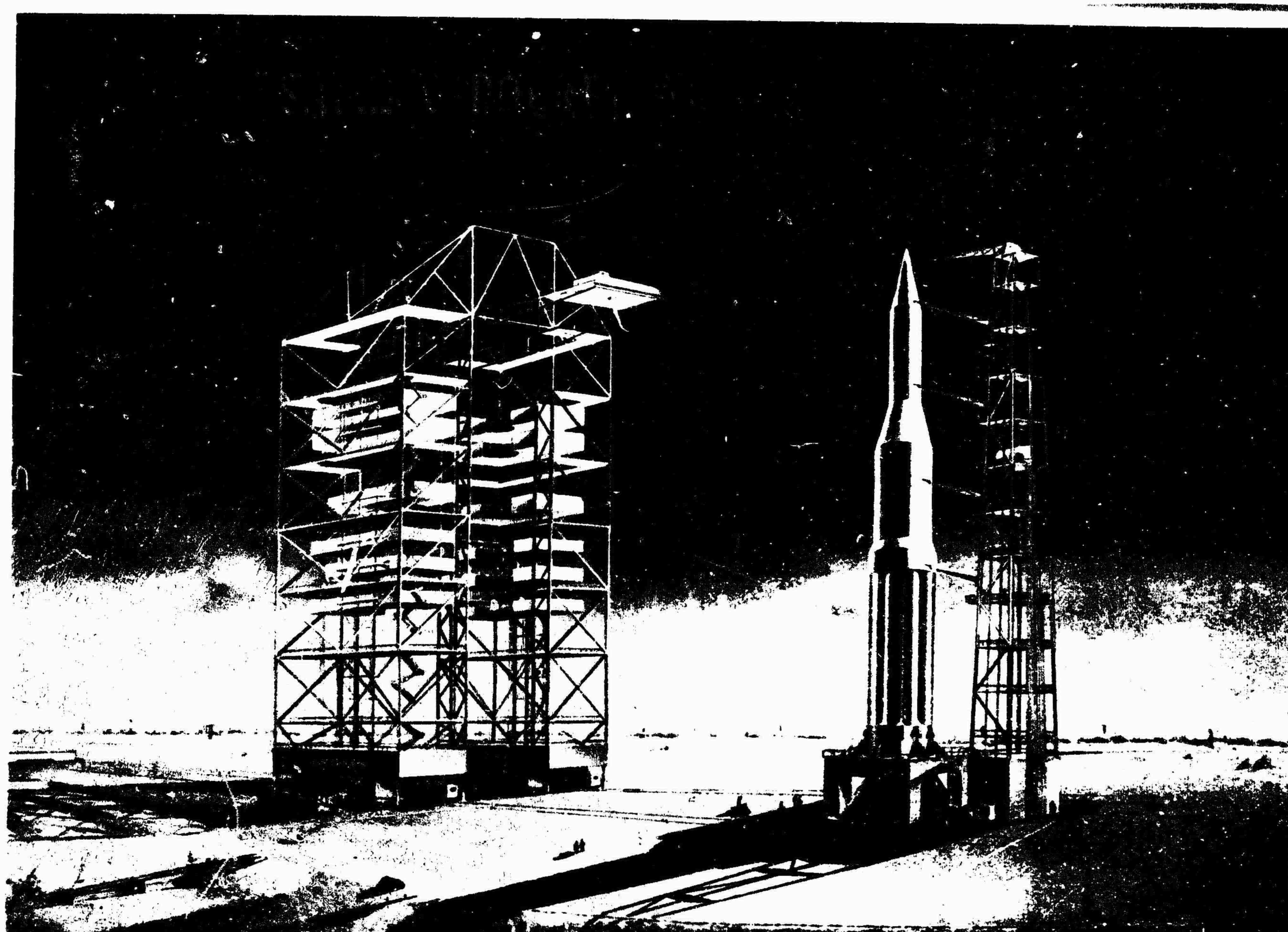
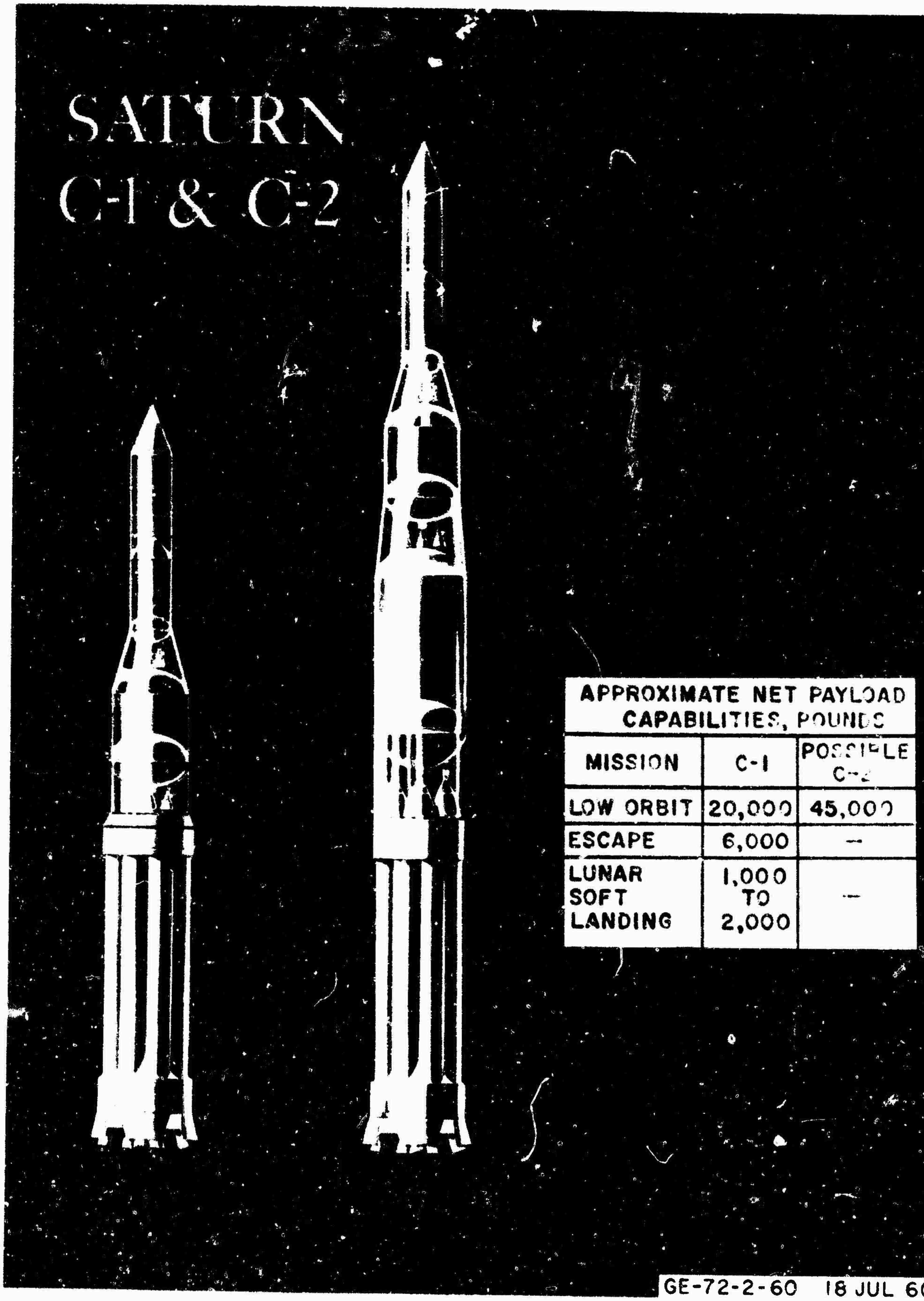



FIGURE 1




| APPROXIMATE NET PAYLOAD CAPABILITIES, POUNDS | | |
|---|---|---|
| MISSION | C-1 | POSSIBLE C-2 |
| LOW ORBIT | 20,000 | 45,000 |
| ESCAPE | 6,000 | — |
| LUNAR SOFT LANDING | 1,000 TO 2,000 | — |

FIGURE 2

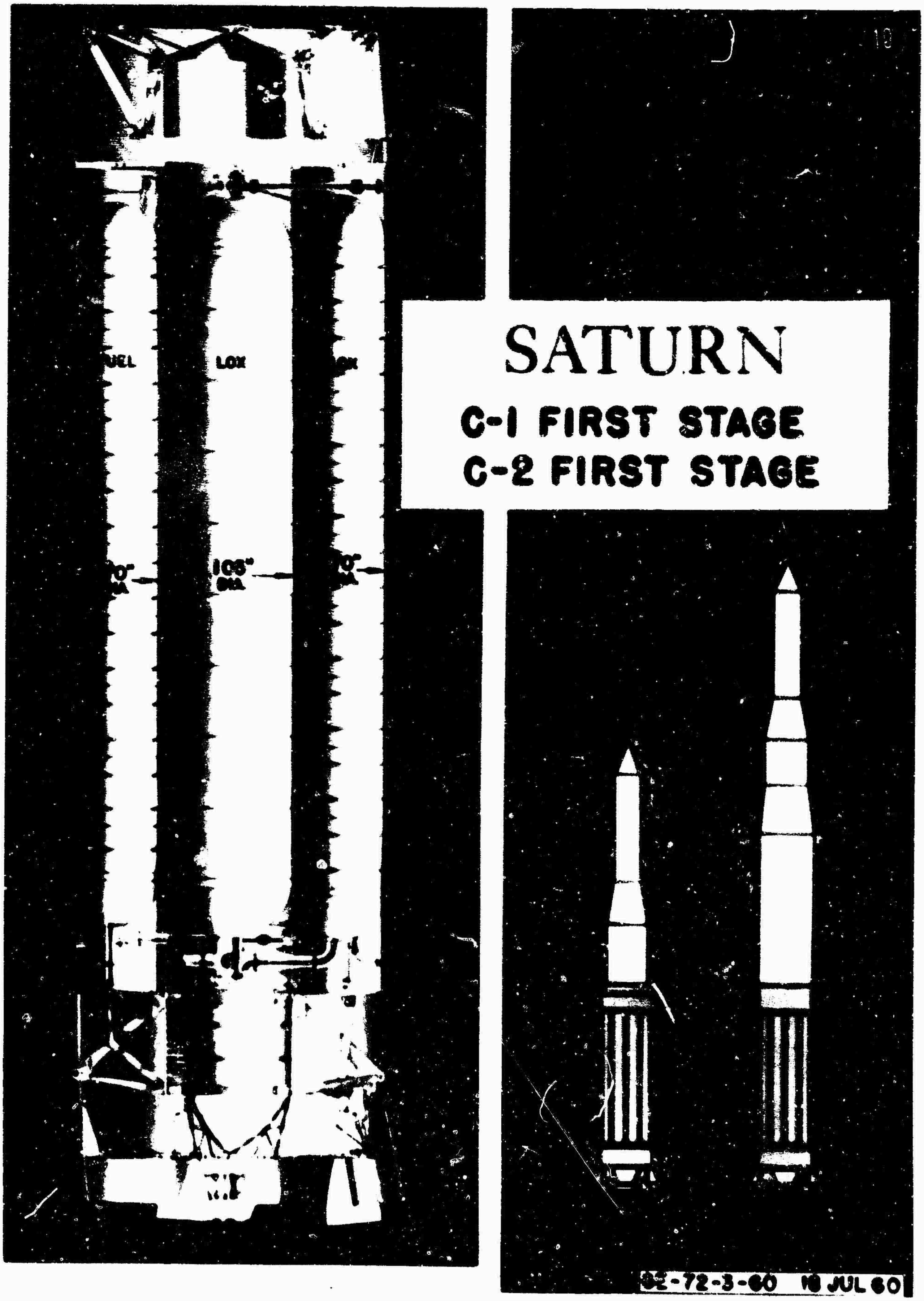



FIGURE 3

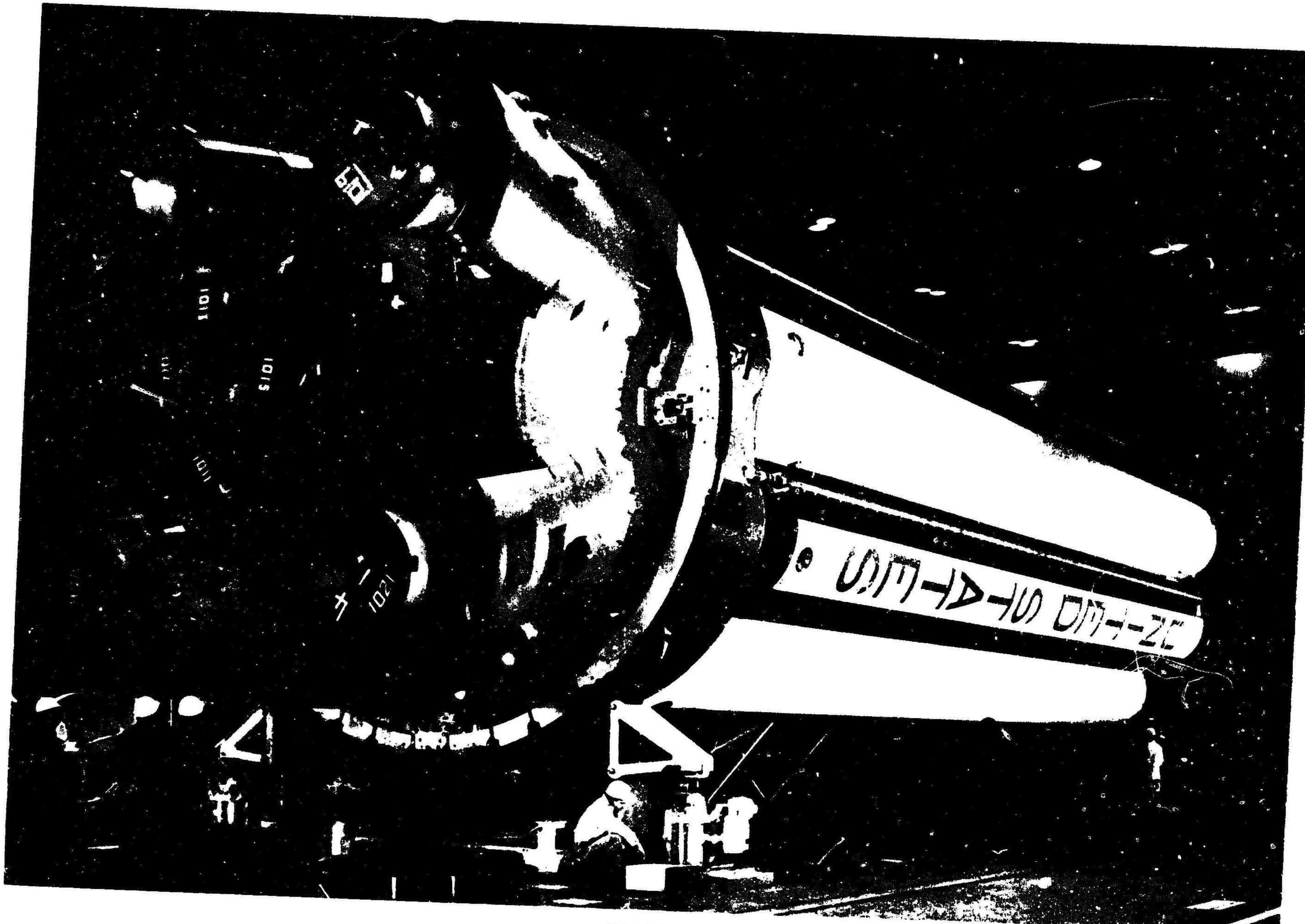



FIGURE 4

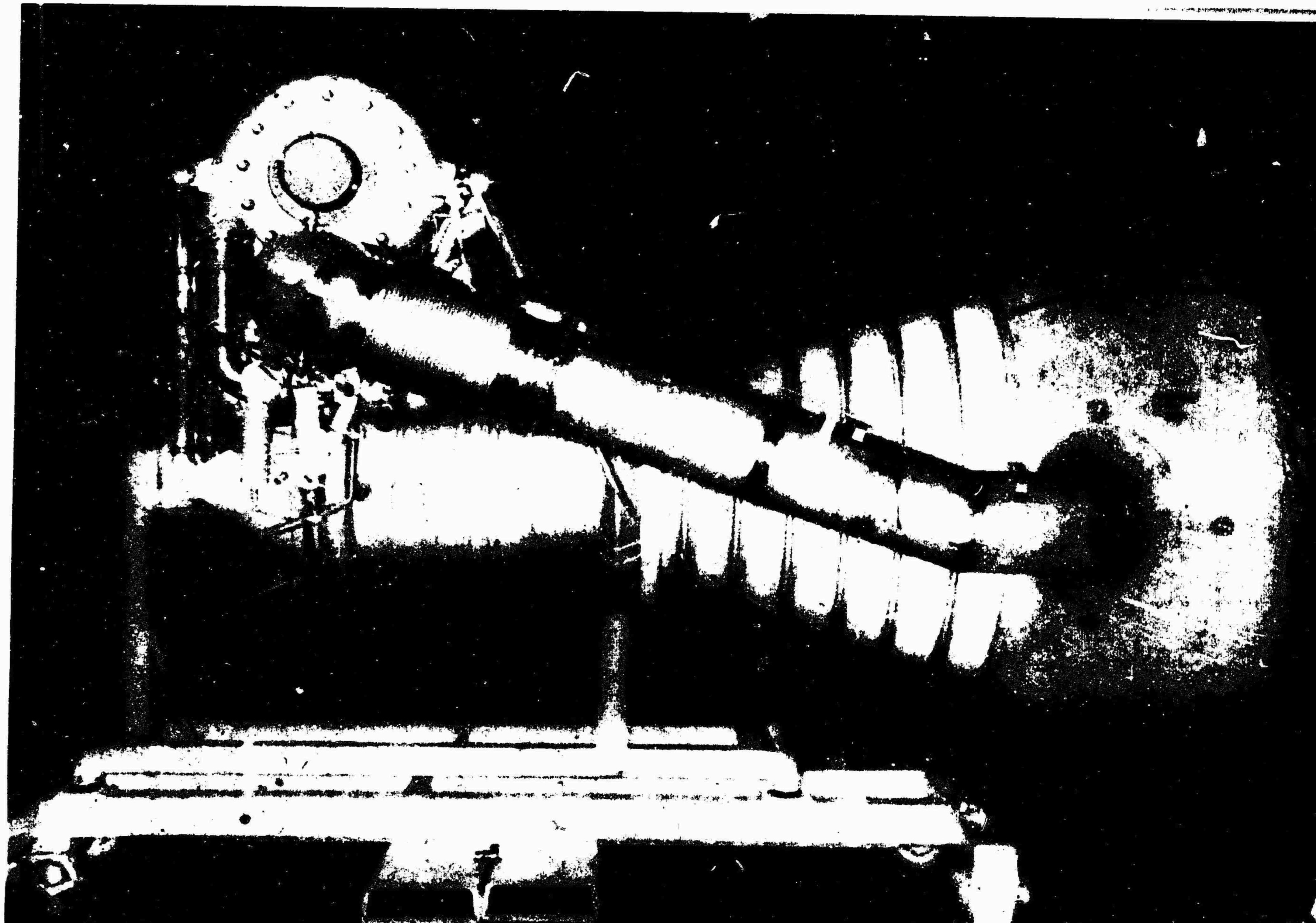


FIGURE 5

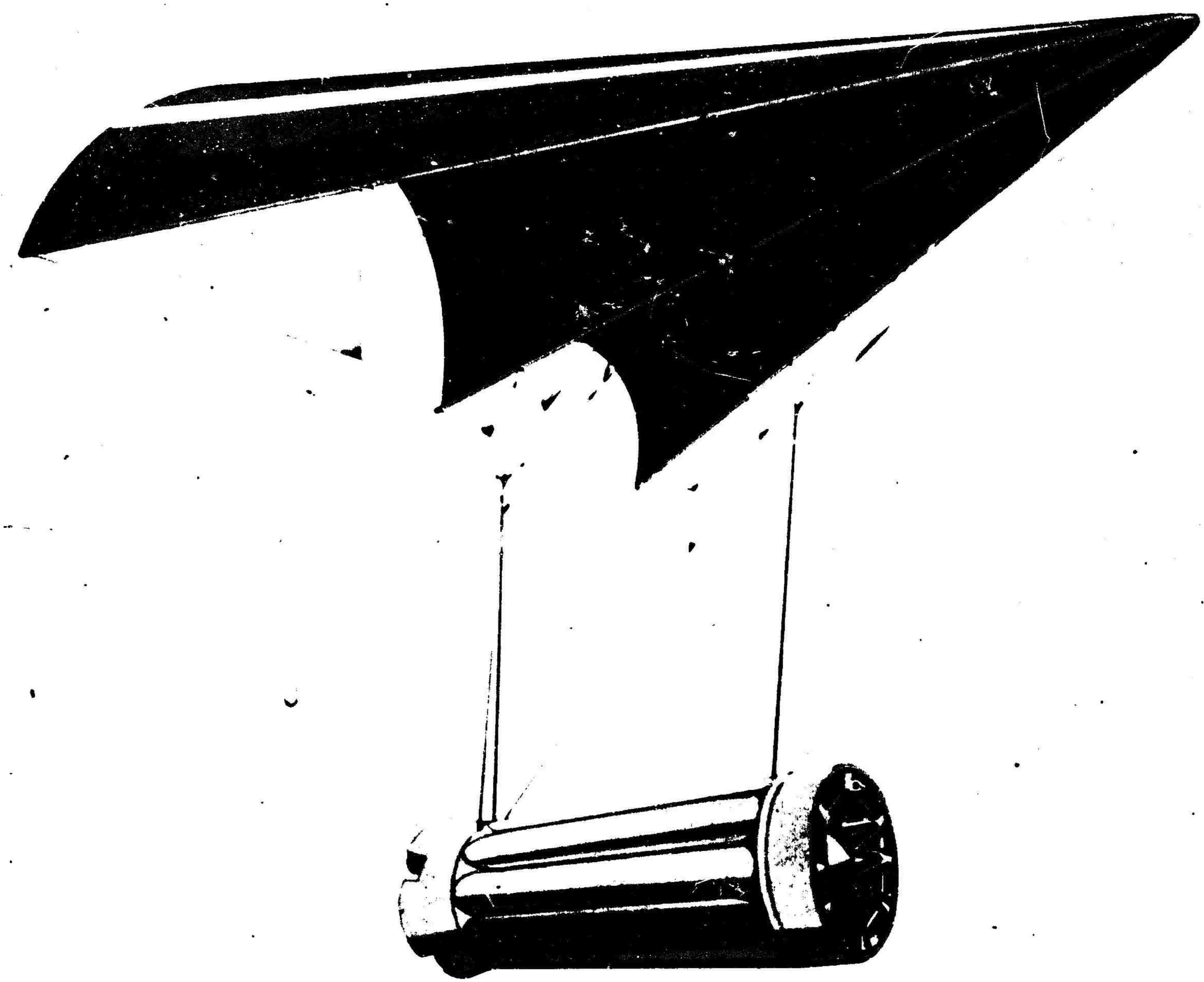


FIGURE 6

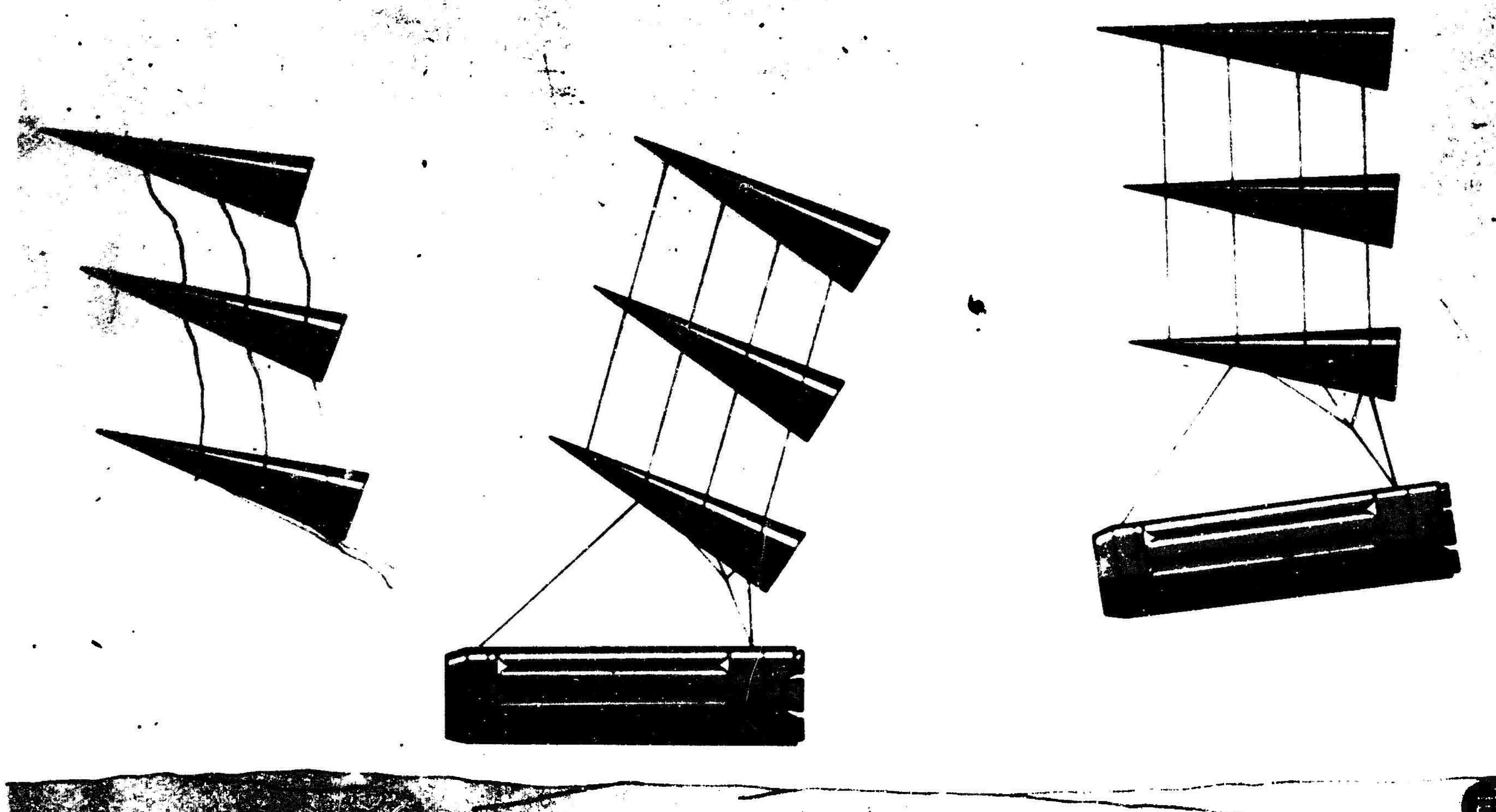


FIGURE 7

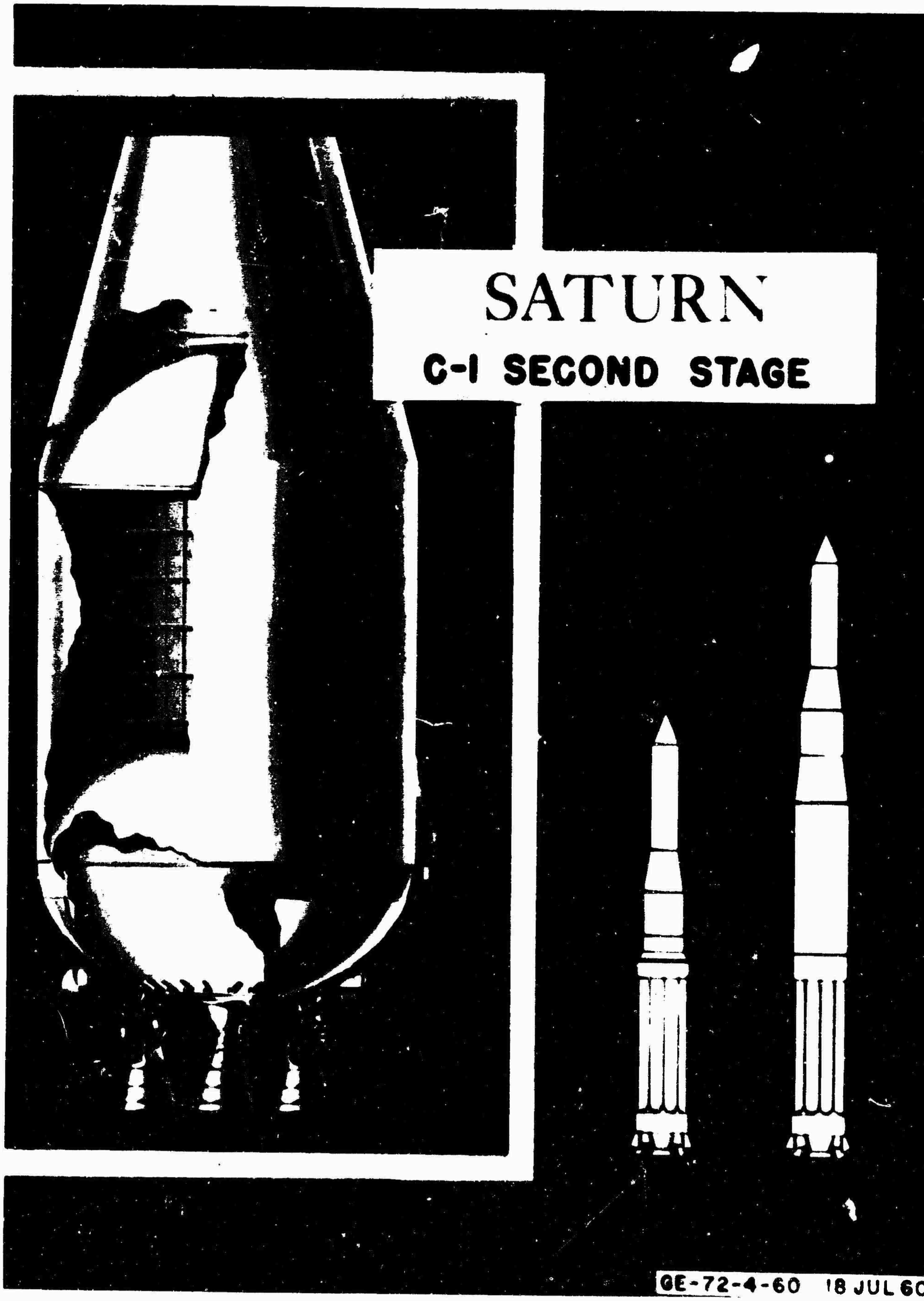



FIGURE 8

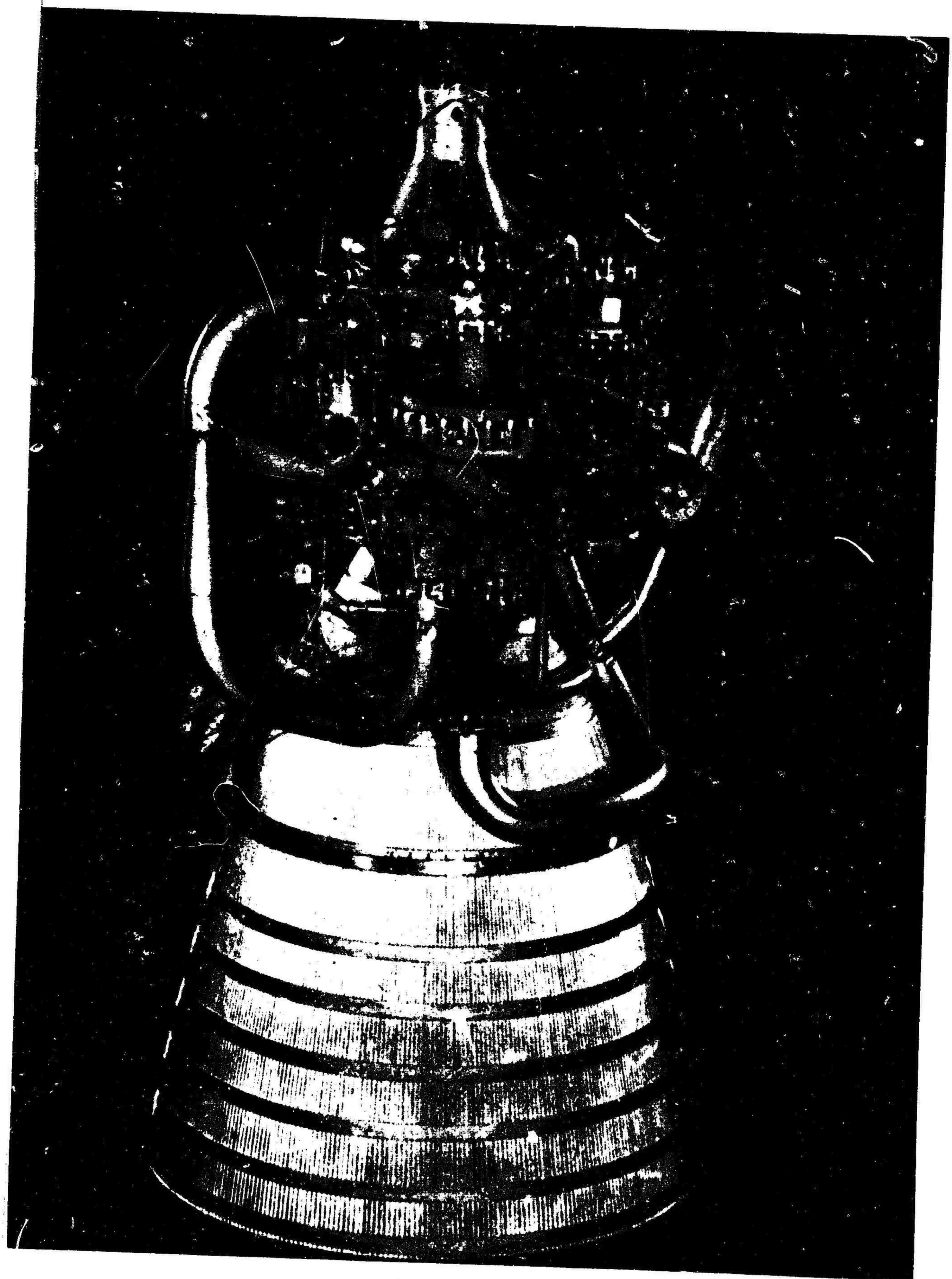


FIGURE 9

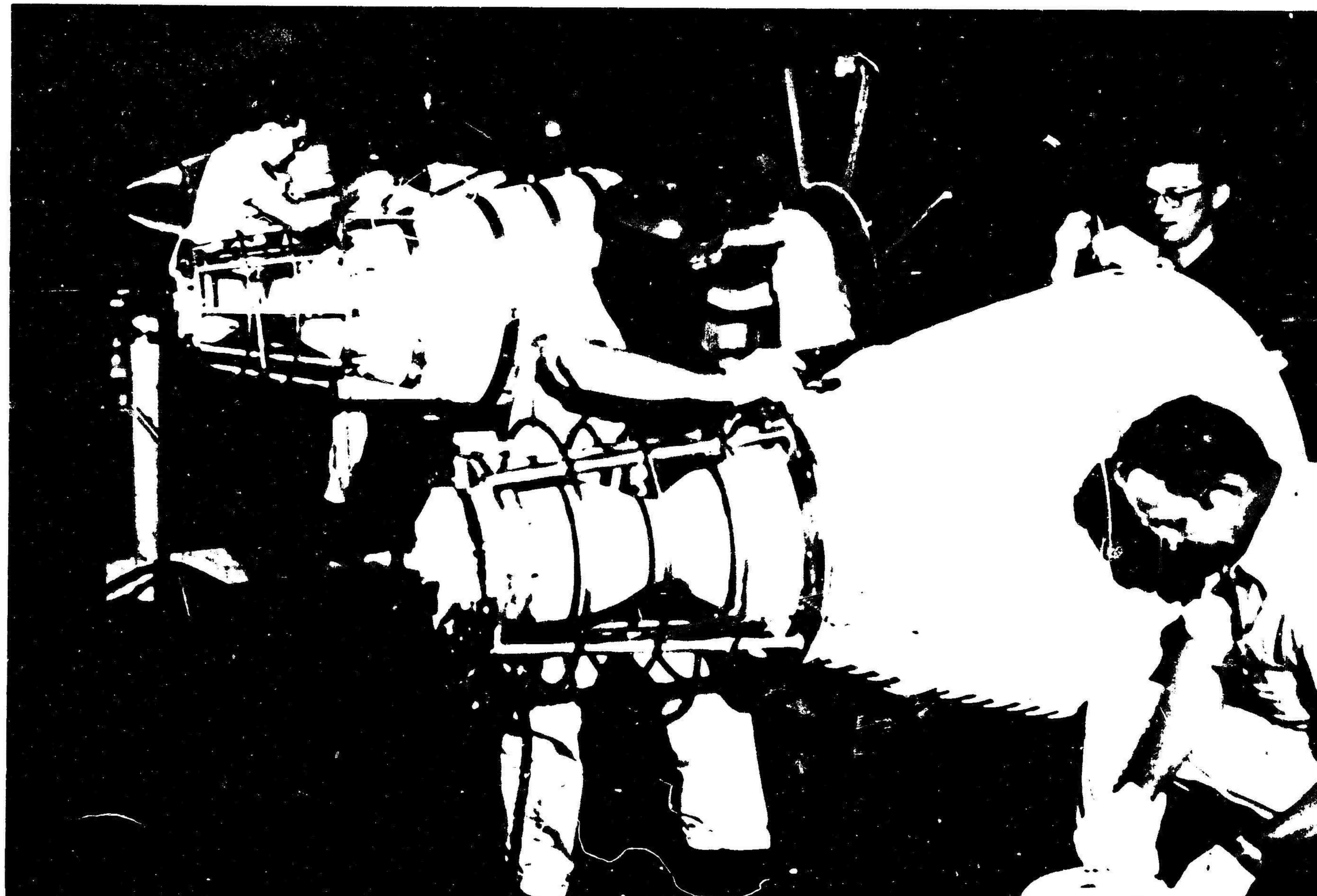


FIGURE 10

FIGURE 11


FIGURE 14A

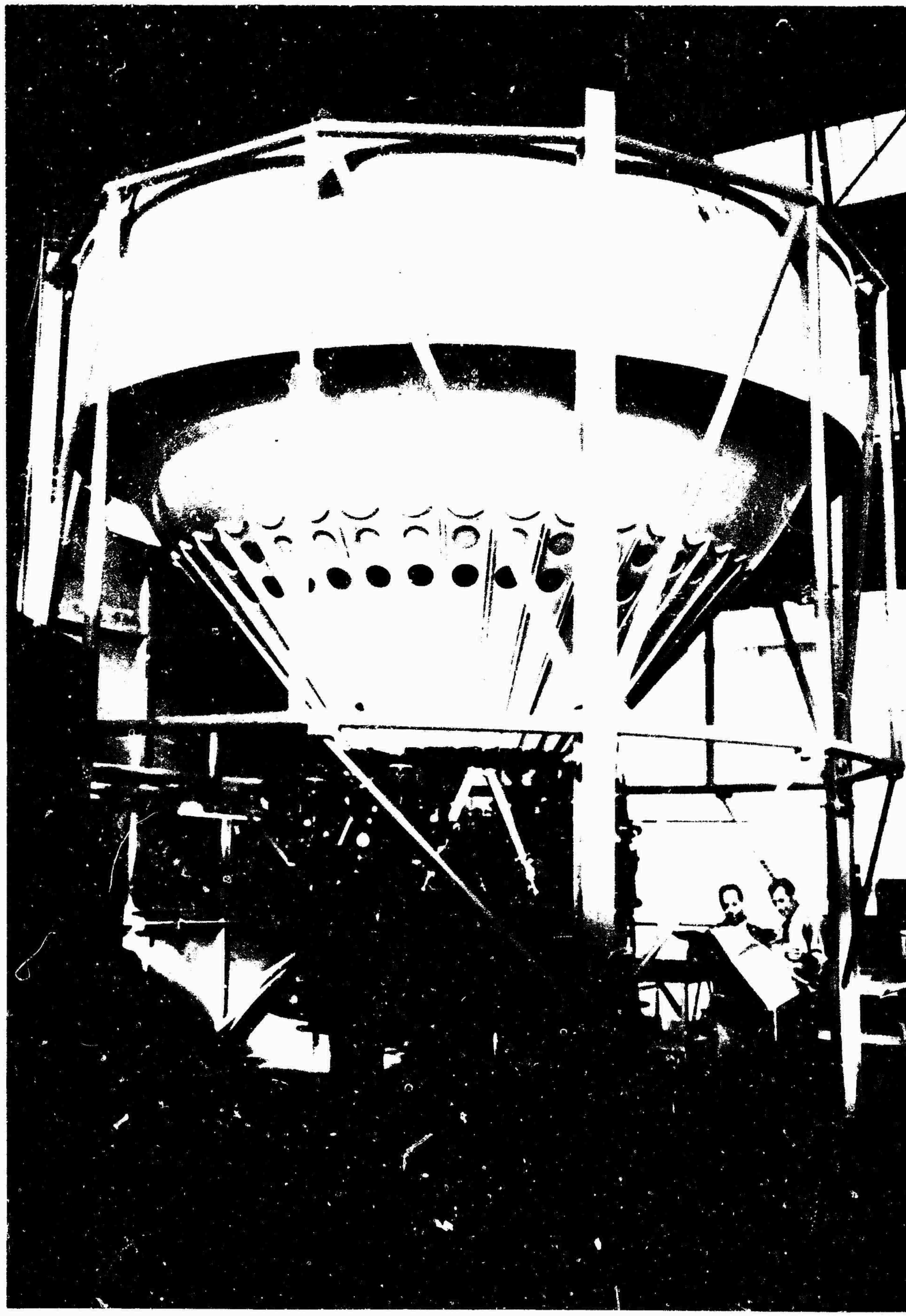


FIGURE 15

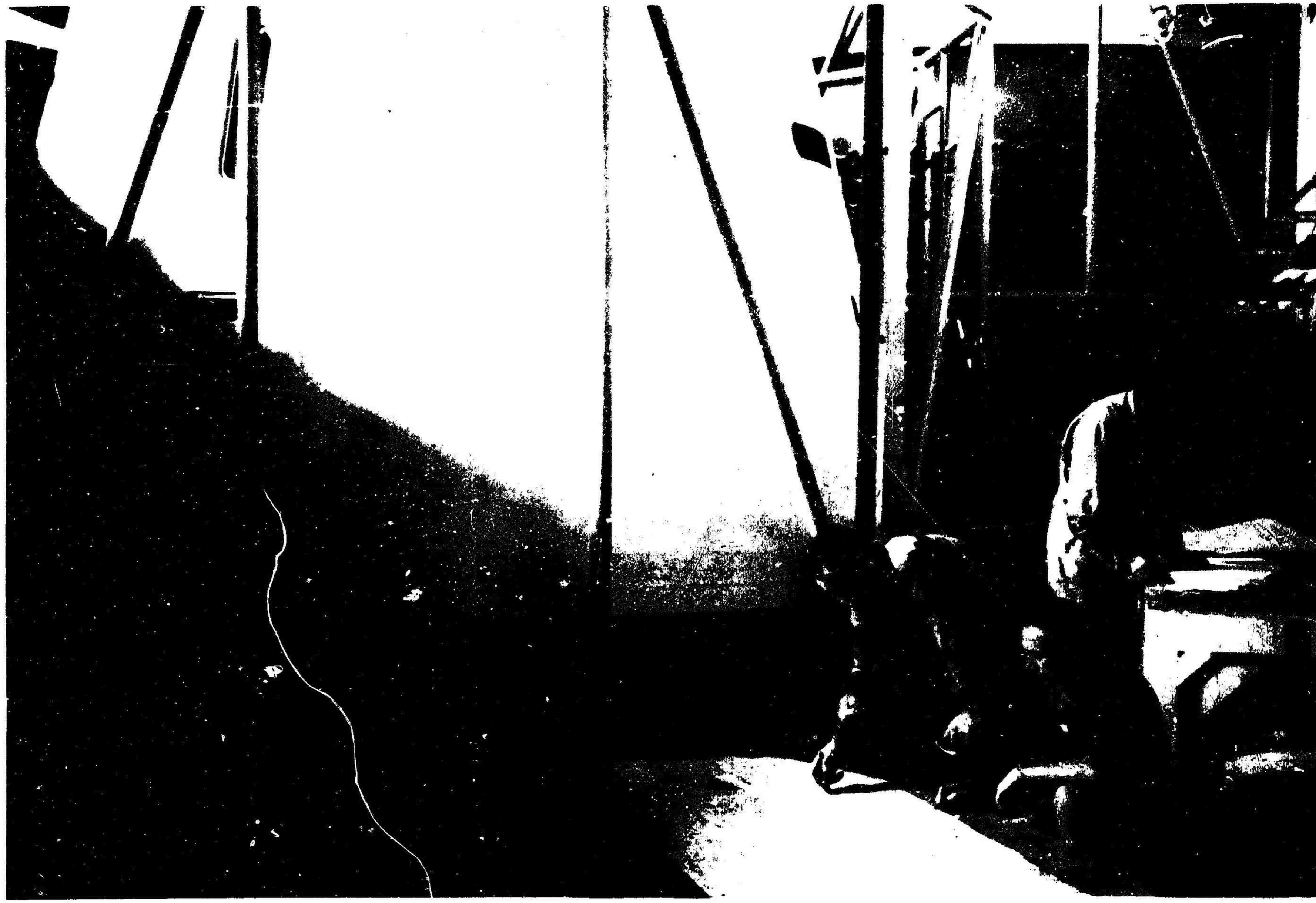


FIGURE 16

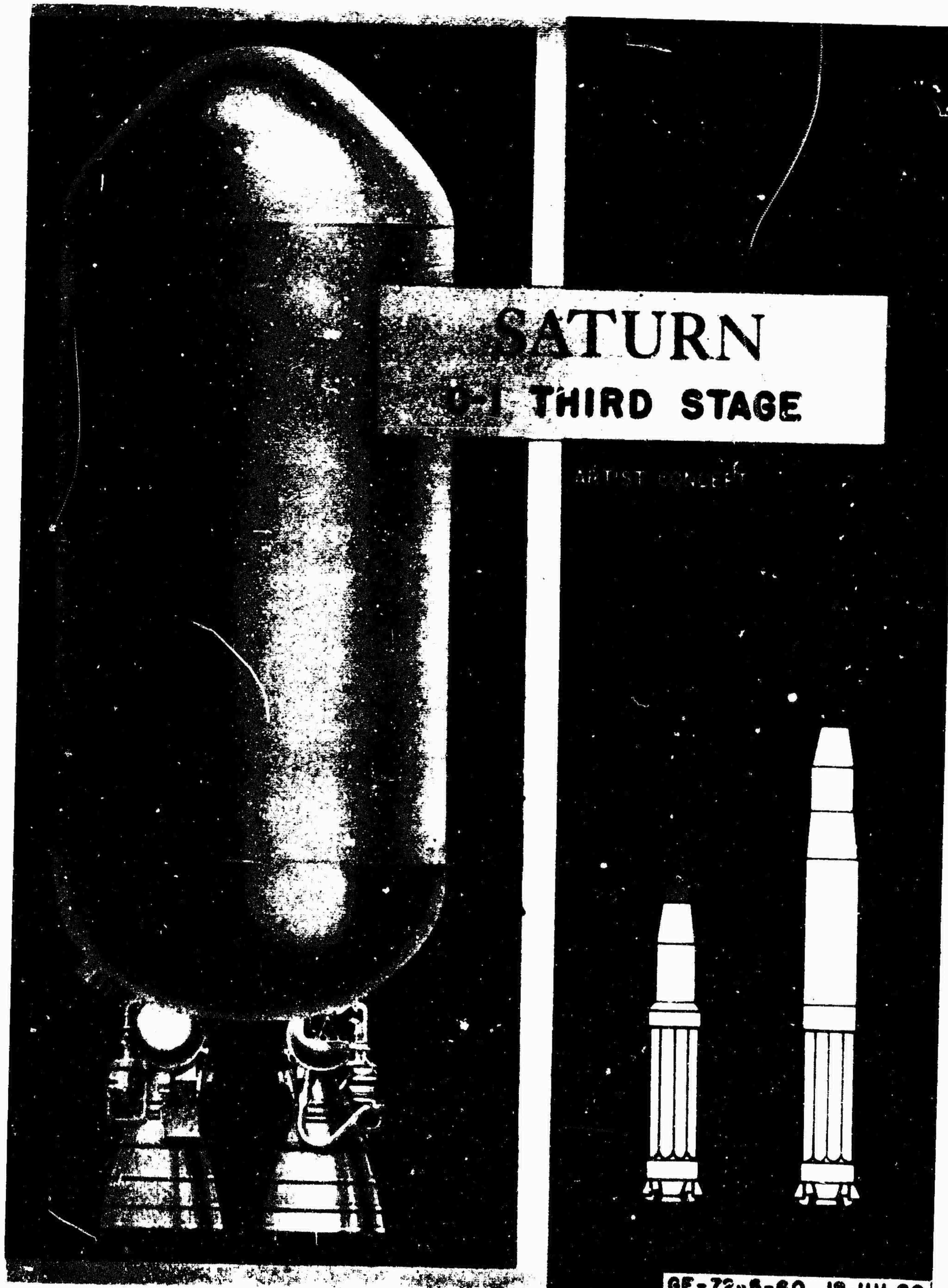



FIGURE 17

FIGURE 18

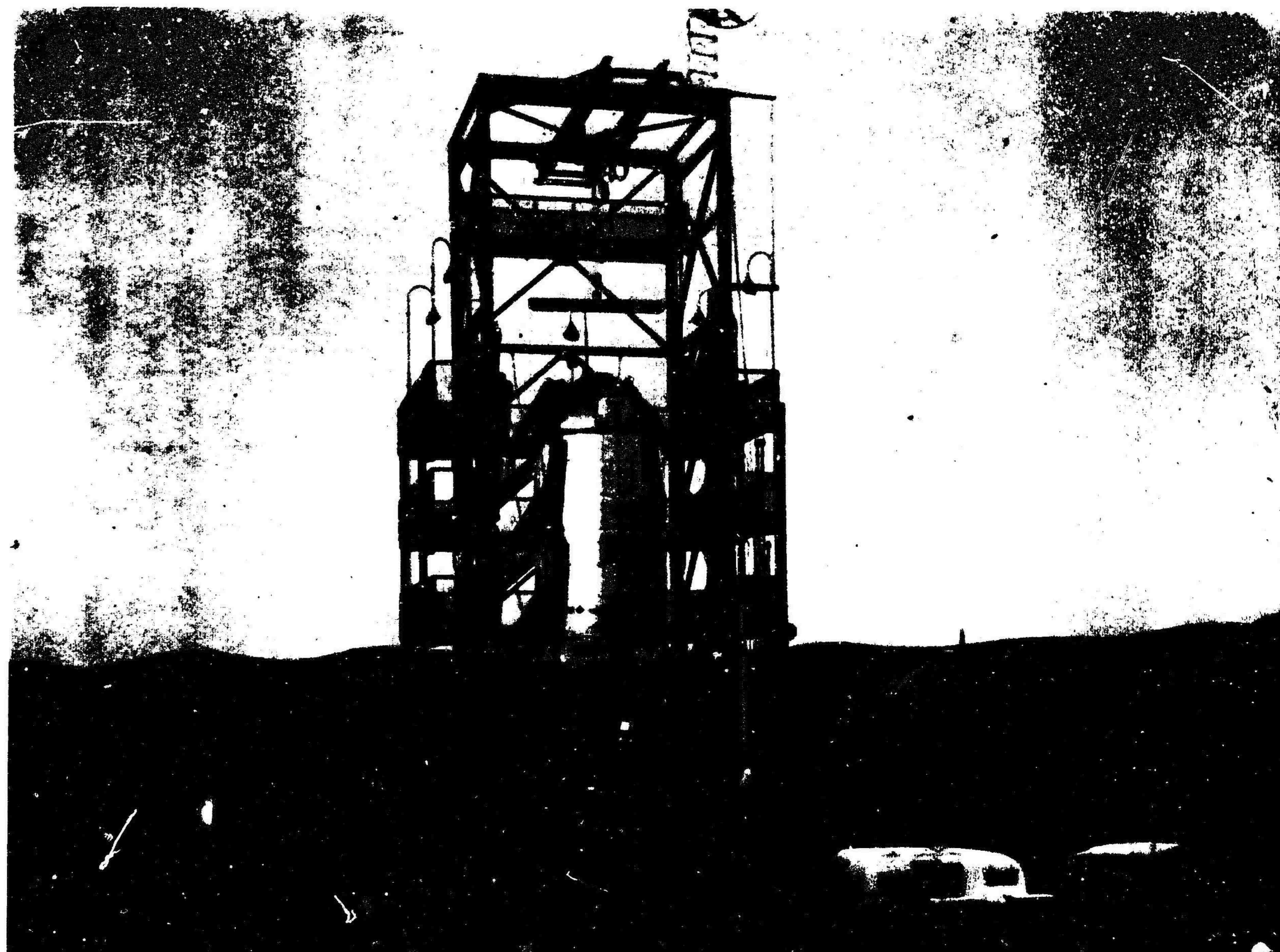


FIGURE 19

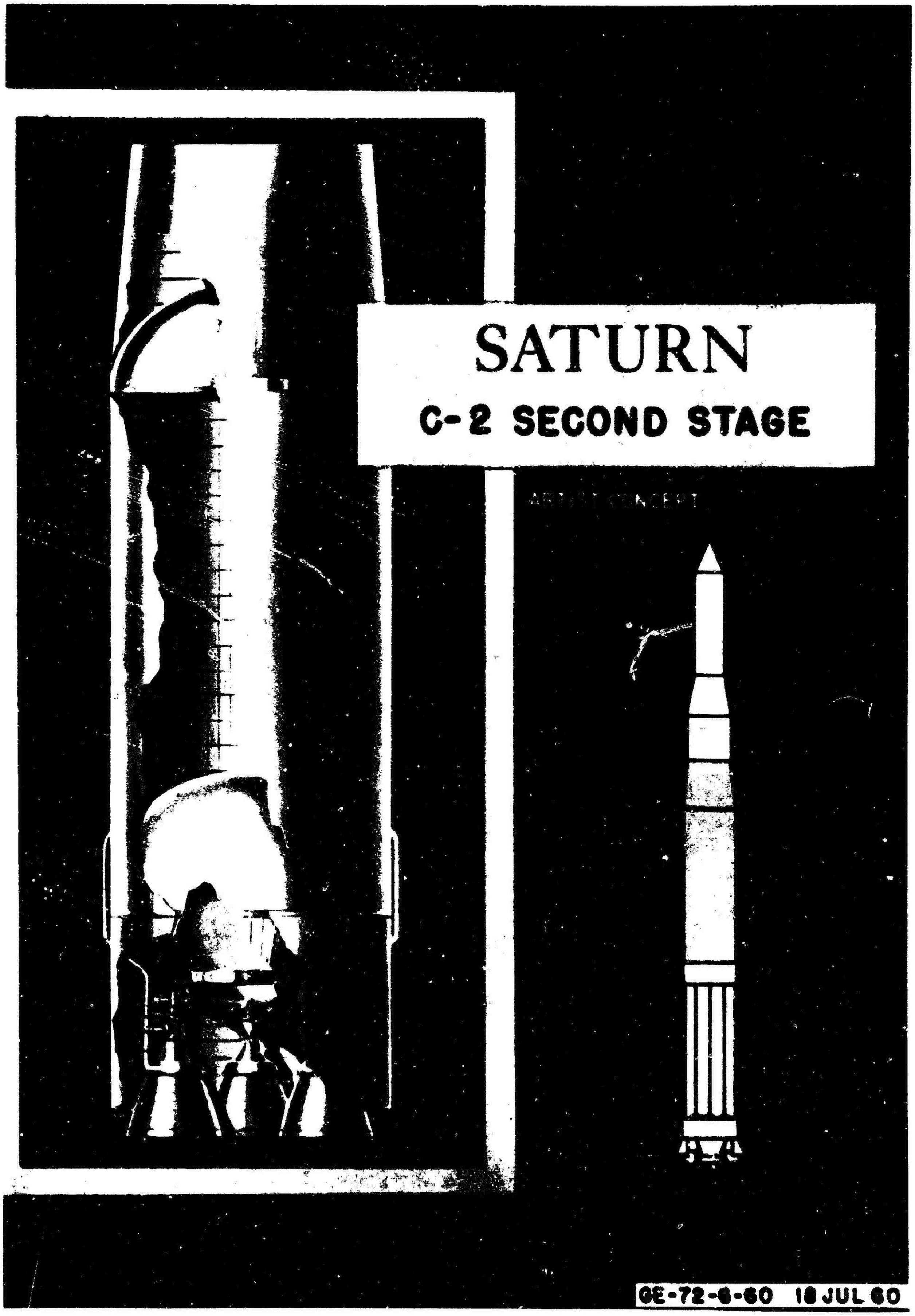



FIGURE 20

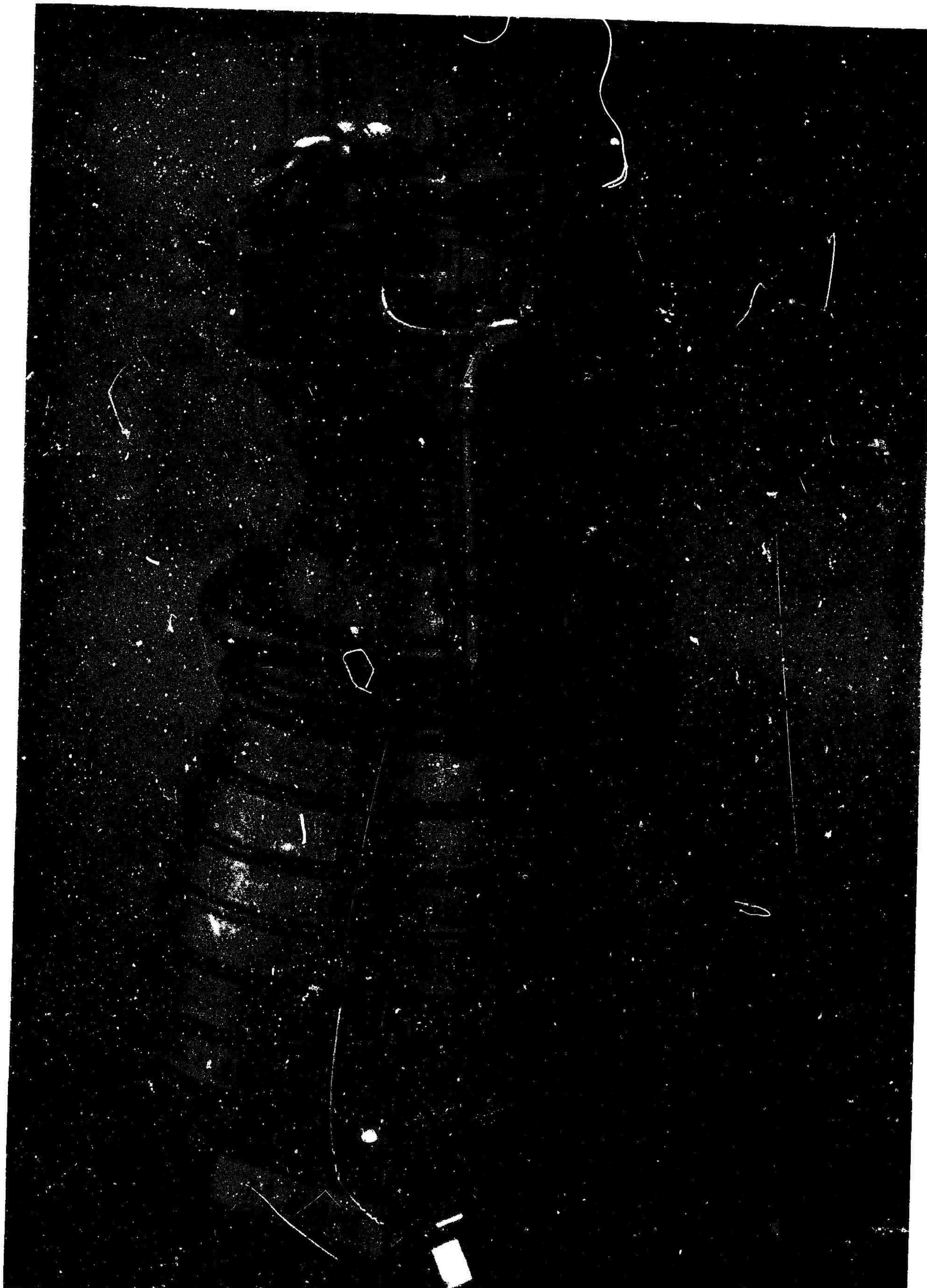
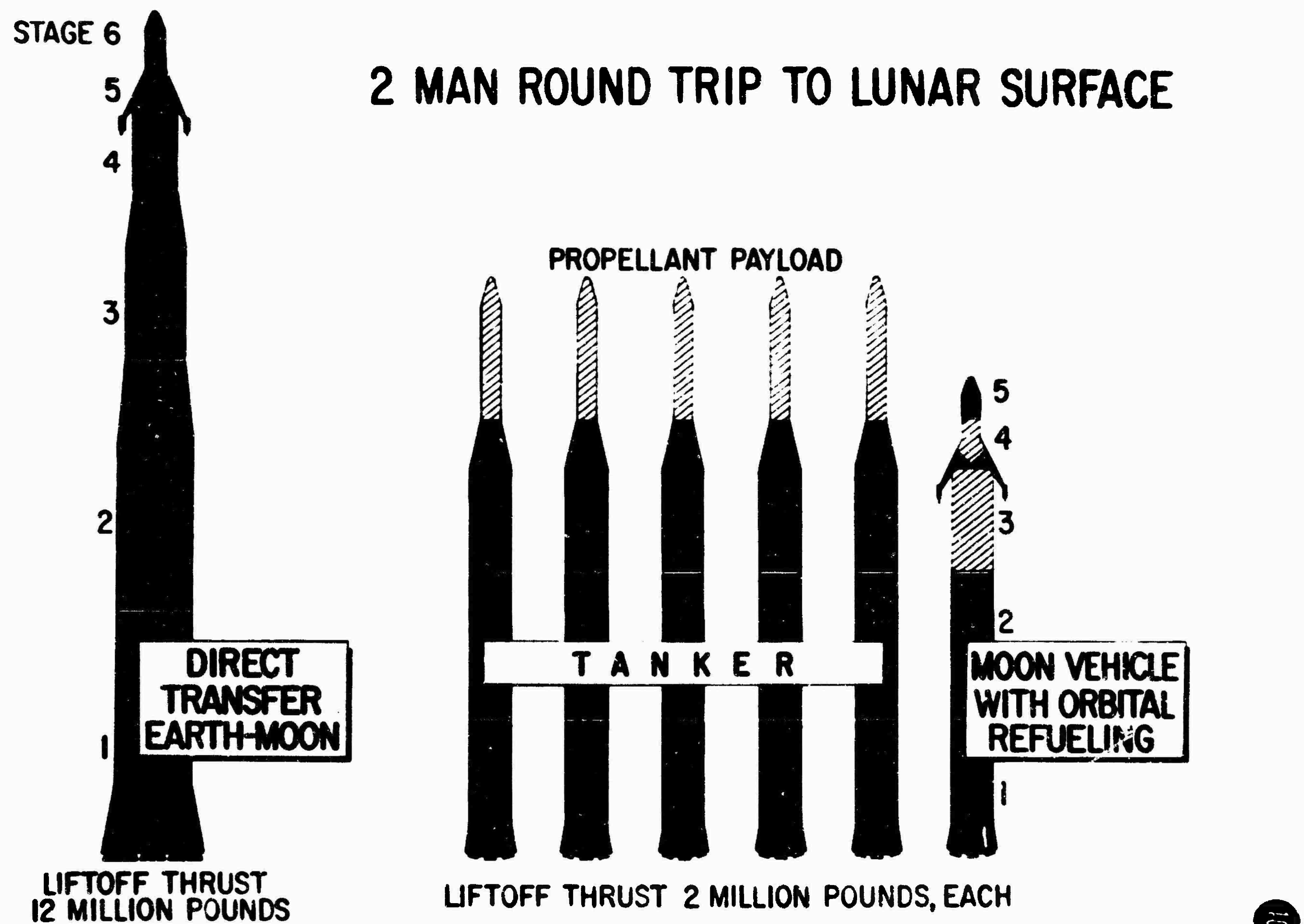


FIGURE 21



2 MAN ROUND TRIP TO LUNAR SURFACE
STAGE 6
5
4
3
2
1
DIRECT TRANSFER EARTH-MOON
LIFTOFF THRUST
12 MILLION POUNDS
PROPELLANT PAYLOAD
T A N K E R
5
4
3
2
1
MOON VEHICLE WITH ORBITAL REFUELING
LIFTOFF THRUST 2 MILLION POUNDS, EACH
GE-72-16-60 18 JUL 60
10


FIGURE 23

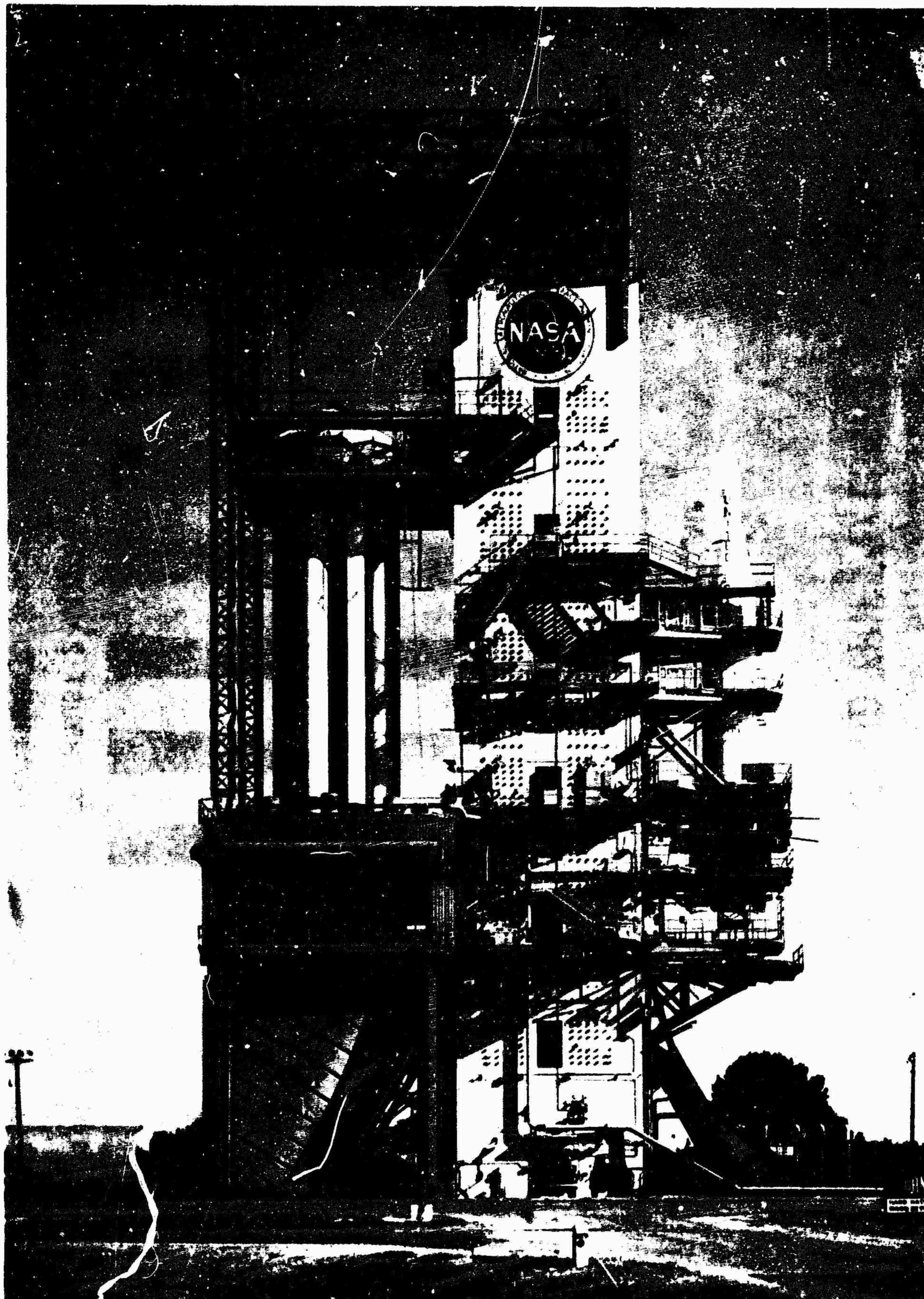



FIGURE 29

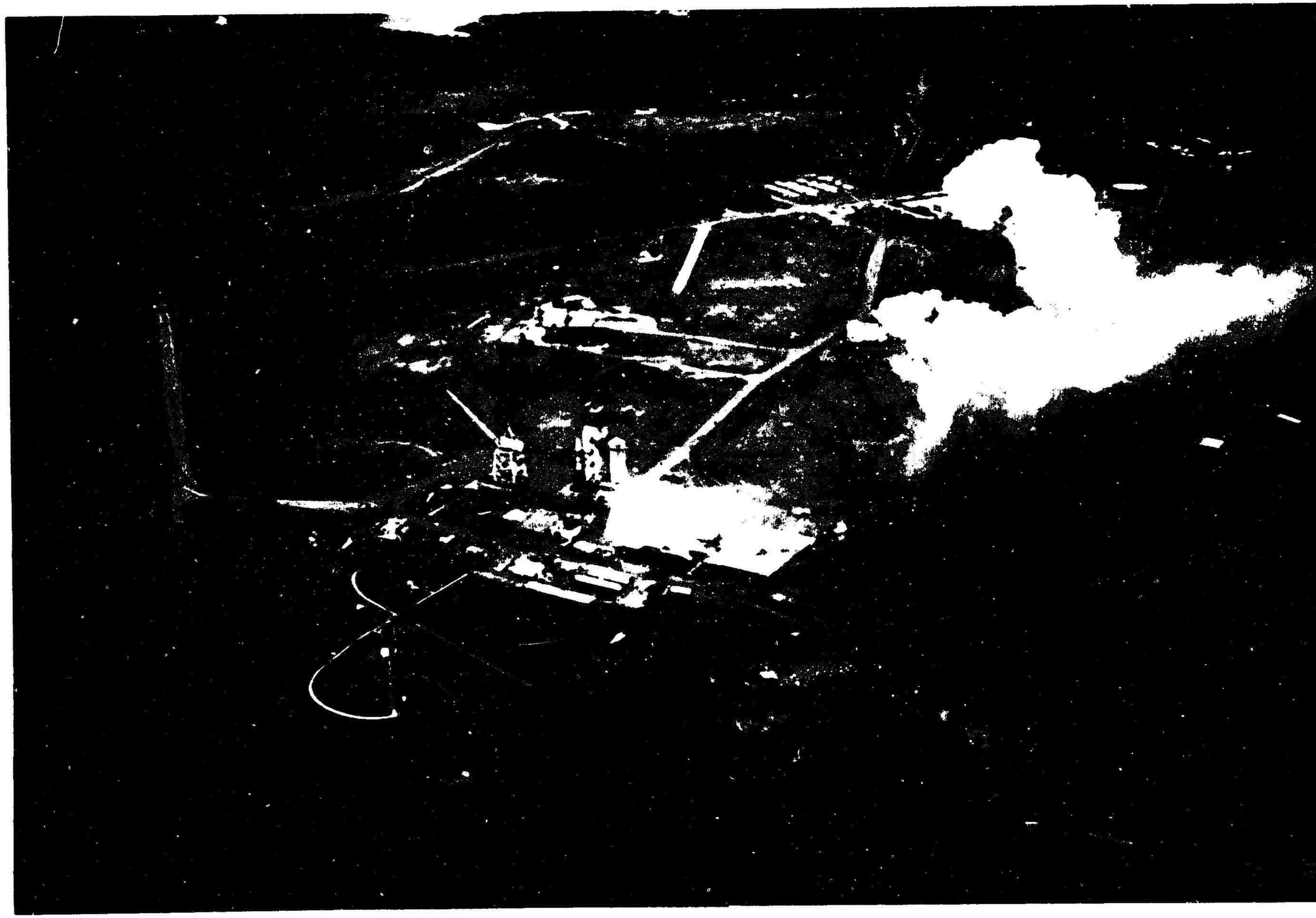


FIGURE 30

FIGURE 31

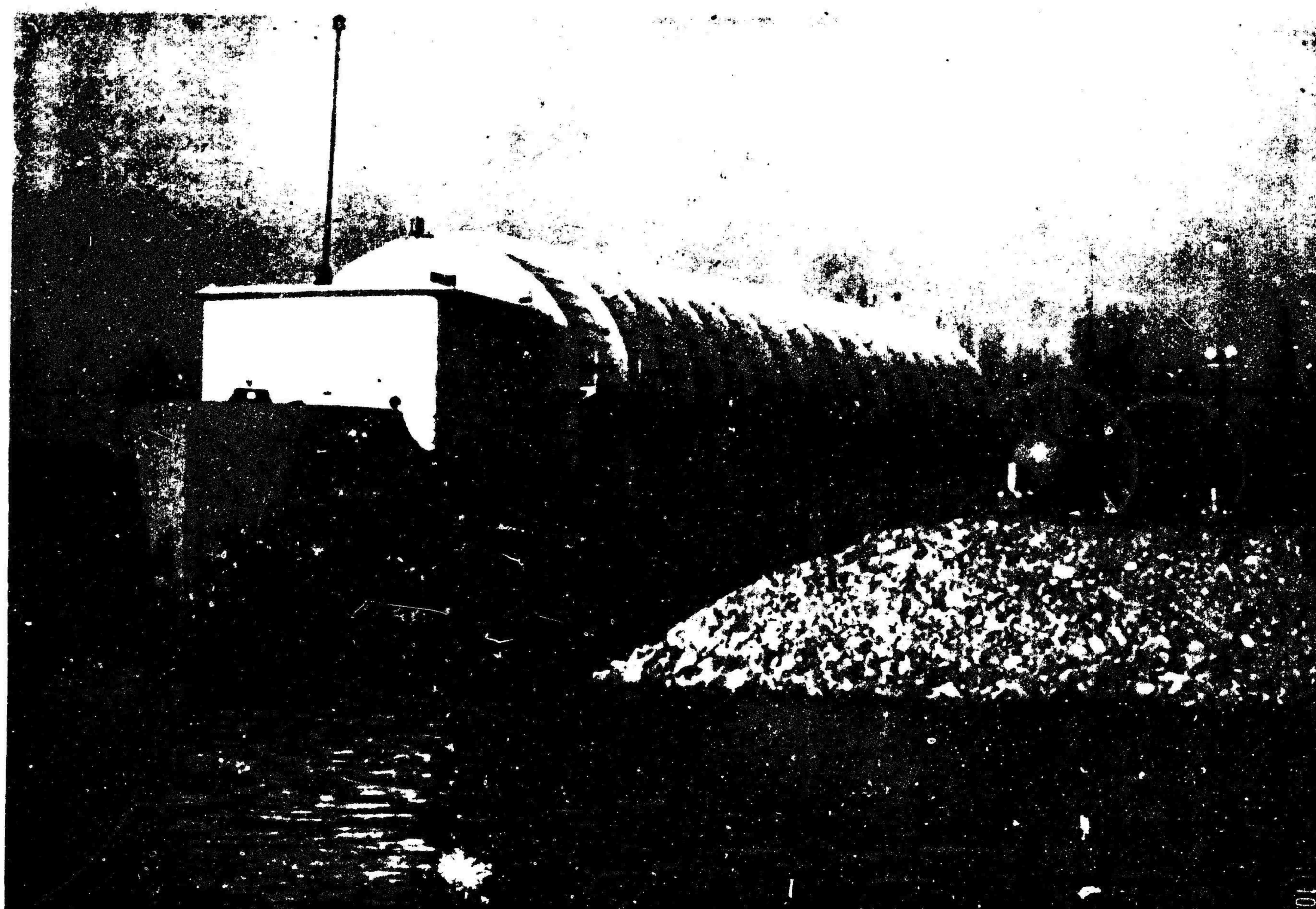


FIGURE 32

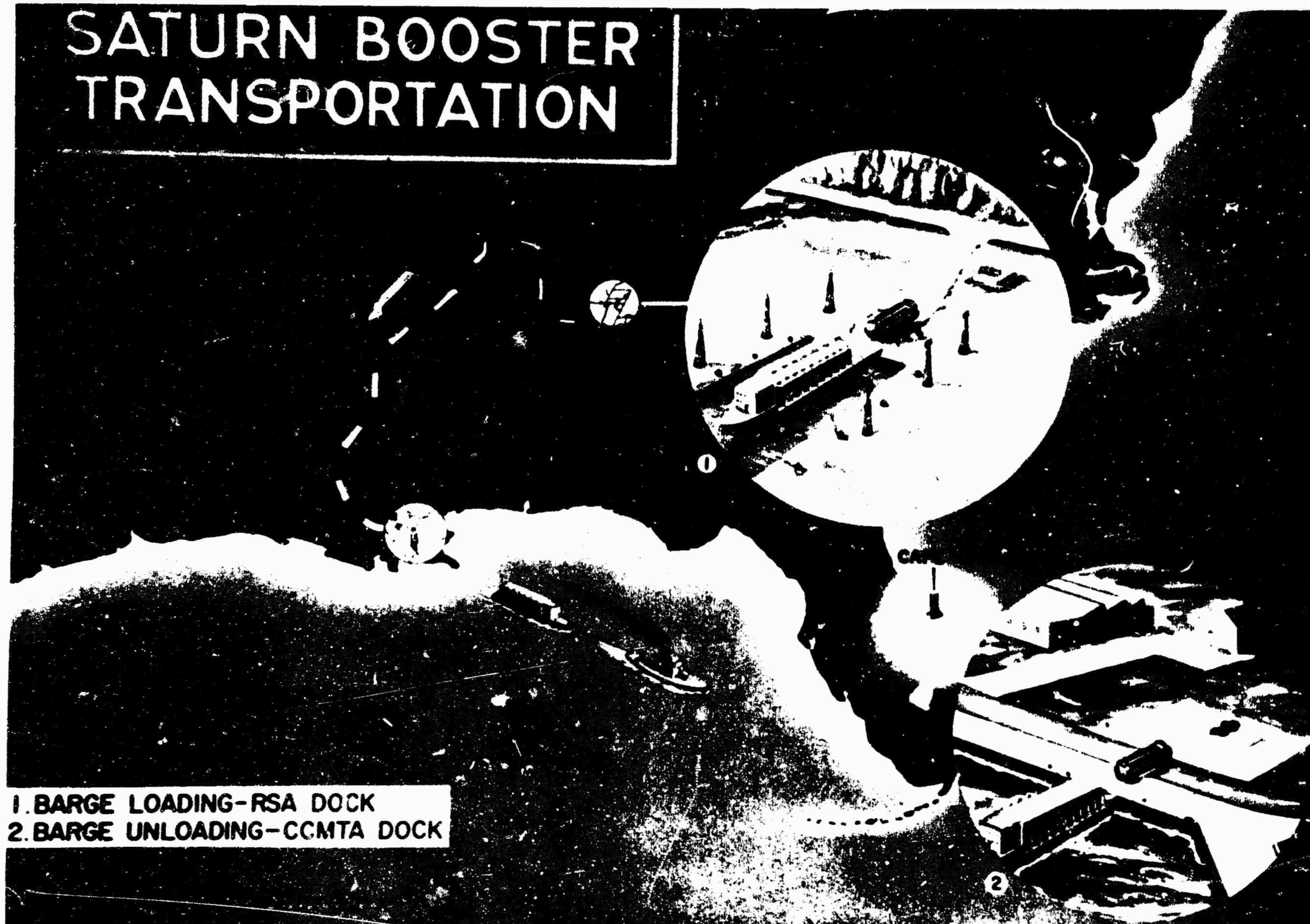



FIGURE 32A

FILE NO. 691-32 Rev. A

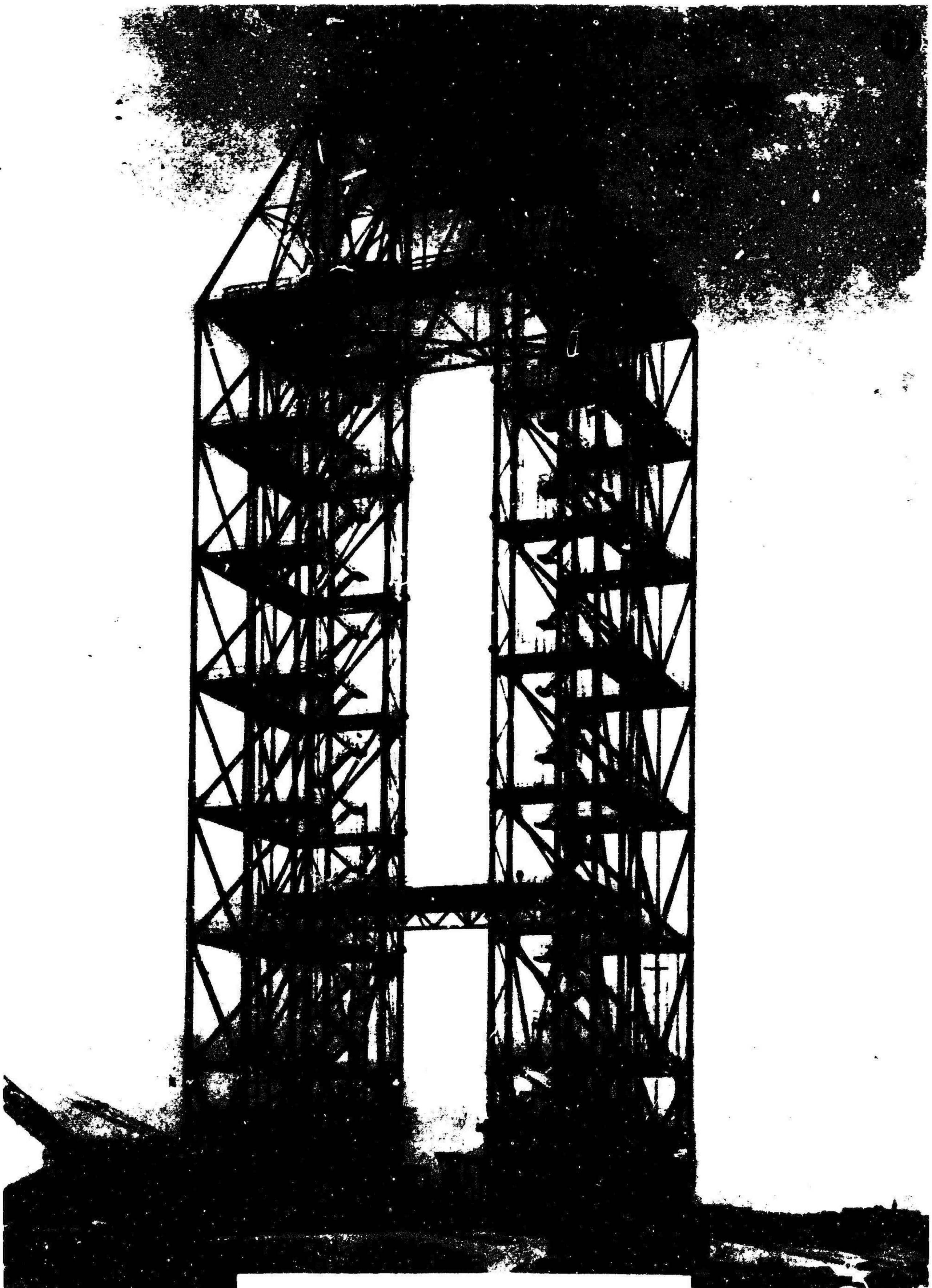


FIGURE 33

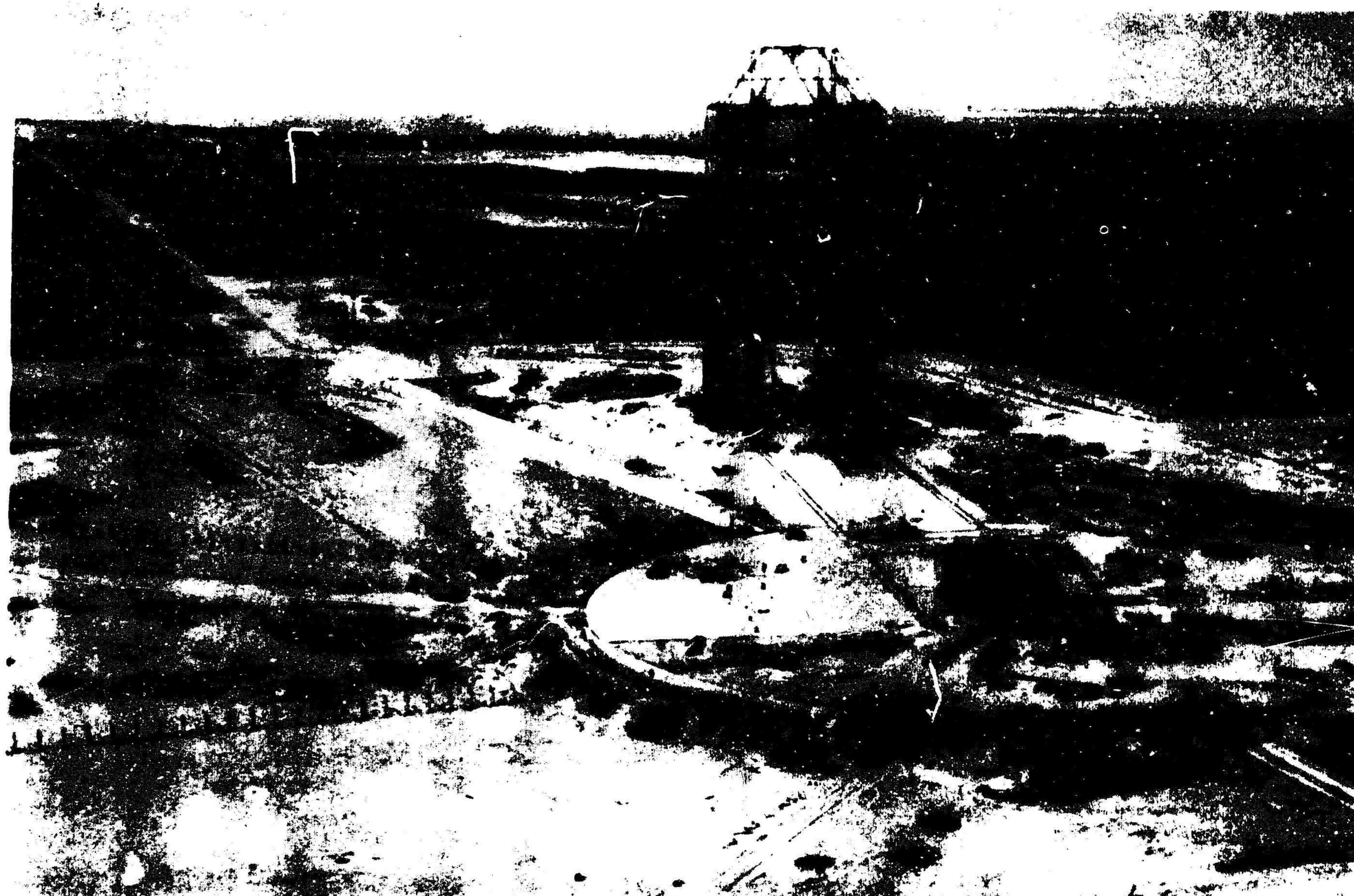


FIGURE 35

11

LECTURES IN AEROSPACE MEDICINE

*THE STATUS OF MAN'S ADVANCE ON THE VERTICAL FRONTIER

Presented By

Brigadier General Don D. Flickinger

Assistant for Bioastronautics

Air Research & Development Command

*This article will be published at a later date.

12

LECTURES IN AEROSPACE MEDICINE

# THE "G" SPECTRUM IN SPACE FLIGHT DYNAMICS

Presented by

Colonel John P. Stapp, USAF, MC

Assistant for Aerospace Medicine

Advanced Studies Group

USAF Aerospace Medical Center

# THE "G" SPECTRUM IN SPACE FLIGHT DYNAMICS

by
Colonel John P. Stapp, USAF, MC

## 1. Introduction

The prospect of extending the scope of basic research directly to universal dimensions by space exploration and experiments offers scientific gains and enhanced international prestige as tangible rewards (Stapp 13).

A multistage-rocket-propelled missile transporting into orbit a capsule having a minimum weight and a maximum of life support will provide the earliest means for manned exploration of space. At least for the first flight, the occupant will endure accelerative stresses that will limit his reliability in controlling the vehicle, relegating him to the role of passive observer. While the urgent need for data from such a flight justifies the highest priority, it is quite likely that only a few such scientific explorations will be needed.

The New World was explored at the price of a queen's necklace. A king's ransom will scarcely cover the cost of putting one manned ballistic spacecraft into orbit with re-entry and recovery. Indeed, such a ballistic vault into space could be compared to solving the problem of crossing the sonic barrier by placing a man in a hollowed-out cannon shell and shooting it to supersonic speed. With great

NOTE: The contents of this manuscript reflect the personal views of the author and are not to be construed as a statement of official USAF policy.

difficulty he might be retrieved unhurt. but he would hardly be willing to repeat the experience. In actuality, the need for supersonic flight determined that a long, arduous transition from subsonic flight by gradual increments of performance in piloted aircraft be the means for evolving present supersonic and hypersonic jet aircraft. Similarly, space exploration in ballistic vehicles derived from applied technical development will differ from space flight under the control of the occupant. In this sense, space flight is a continuous progression by performance increments from aerodynamic flight.

The entire area from the upper limits of aerodynamic flight to the lower limits of orbital space flight can be investigated by such increments. From the standpoint of applied technology, this performance area of higher than aerodynamic flight and lower than orbital velocity trajectory offers the most promise in military and civilian uses combined with scientific objectives. Boost-glide flight above thermal barrier altitudes can span the greatest distance between two points on Earth (12,000 mi.), using only one-fourth the quantity of fuel to attain more than 16 times the speed of a supersonic jet transport covering the same distance within the atmosphere. Vertical ascent missiles can coast to zenith altitudes of 100 to 200 mi. using

only 1/16th the power required to attain the same heights at orbital velocities. The implications respecting boost-glide weapons and space transports on the one hand and photo-reconnaissance and meteorological observations on the other become obvious.

The recent developments in the use of thrust for lift suggest another approach to piloted flight in this performance area. These developments include vertical take-off jet and rocket power for aircraft which are lifted off to a point where transition to aerodynamic lift can be accomplished in the air either by rotating the thrust units or by a 90 degree change in attitude of the aircraft. The principle of using thrust to provide lift as well as translational propulsion and guidance can be projected to pressure altitudes beyond aerodynamic lift. The pull of gravity on the vehicle can be offset by propulsion system thrust. This thrust has the advantage of being independent of translational velocity in contrast with aerodynamic lift. A platform, for observers and instruments, hovering at altitudes higher than plastic balloons can attain, with sufficient payloads, would have many uses. By calculation, 1,000,000 cu. ft. of helium can lift 1 lb to 220,000 ft; in practice a payload of almost 500 lbs ha been lifted to an altitude of approximately 140,000 ft. The use of thrust-lift permits vertical ascent independent of horizontal velocity from 135,000 ft. up

to the maximum altitude that such a space platform could rise. This infers development of reaction stabilization and controls by means of thrust modulation or multiple reaction jets.

With existing and immediately foreseeable propulsion systems, the duration of thrust-lift flight would be limited to the order of minutes, minimizing requirements for life support in the cabin inclosure. With modulated thrust, accelerations can be kept within accepted limits for aerodynamic flight, allowing dependable human performance for pilot control of all phases of flight except automatic stabilization of the platform. Such a device would also make an ideal space flight trainer for two or more pilots, superior to any simulator. Such a real-time device could even be used to monitor and calibrate performance of ground-level space-flight computer-simulators.

A crude beginning could be made with off-the-shelf items lashed together for comparatively low-level feasibility studies. A two-man capsule equipped with racks of jato boosters could be balloon-lifted to maximum altitude, and above the balloon release point the jato boosters could then be fired in relays to reach successively higher altitudes. The spent jatos could be dropped and the capsule

recovered by parachute after stabilized free fall to a suitable altitude.

A more advanced vehicle with higher performance could be devised by modifying an existing liquid-fuel rocket engine to permit manually controlled thrust modulation through a useful portion of its thrust range, from 30 to 100 percent as an arbitrary example. With thrust modulation between 15,000 and 45,000 lbs, a two-man vehicle with a gross starting weight of 25,000 lbs, of which 3,000 lbs would be capsule and occupants, can attain more than 500,000 ft altitude without exceeding 5,000 ft/sec velocity of ascent. During descent, the merits of various retro-thrust and drag-type stabilizers can be investigated. Capsule and propulsion unit can be recovered separately from acceptable parachute deployment heights. With such a vehicle, appreciable weightlessness of several minutes duration could be experienced during free fall from zenith.

The anticipated development of much more efficient propulsion systems will enable more prolonged and better controlled thrust-lift flight. An ideal flight path would consist of ascending at low acceleration to the desired height, avoiding thermal-barrier effects by programming velocity during passage through the atmosphere, gradually adding to the translational component until the desired velocity

vector toward destination is attained. Except for brief exposure during ascent and descent, weather is entirely avoided by such a vehicle. With adequate propulsion, passenger space transports using the thrust-lift principle combined with the translational vector could conceivably give comfortable ascent and descent and compress the travel time between any two points on Earth to less than 2 hours, excluding of course, transportation time between the spaceport and town. An applied technical development program along these lines would provide platforms for testing and developing components of space weapons and space transports while training numbers of space pilots in real-time flight at comparatively low cost. Such a program would establish a desirable basic trend of adapting machine performance to human normal operating ranges of acceleration. This is in contrast with the necessity for selecting and training exceptional pilots and observers to compress themselves to the confines of minimum life-support capsules within which they endure multiple-stage ballistic propulsion accelerations found optimum from engineering standpoints for attaining orbital or escape flight trajectories.

2. Accelerations to Orbital and Escape Velocities

To attain a circular orbit 200 to 250 kilometers (125-155 miles)

above the earth, an artificial satellite must be accelerated to a velocity approximating 8 kilometers per second (4.97 miles per second) before centrifugal force comes into equilibrium with the mass of the satellite along the orbital path. This would require a calculated constant acceleration of 828 g seconds. To reach escape velocity a velocity of 11 kilometers per second (6.83 miles per second) must be attained. 1152 g seconds of calculated constant 1 g acceleration will be needed to attain this velocity.

Orbital and escape velocities respectively within 2-10 minutes of calculated constant acceleration would demand the following g-time exposures:

| Minutes | g to orbit | g to escape |
|---|---|---|
| 2 | 6.9 | 9.6 |
| 4 | 3.45 | 4.8 |
| 6 | 2.3 | 3.2 |
| 8 | 1.73 | 2.4 |
| 10 | .828 | 1.15 |

Gauer and Ruff in 1939 [6,8] exposed human subjects to 11 g for three minutes in the transverse, front to back orientation, or supine position, without reaching a tolerance limit, indicating that

the theoretical g time exposures for both orbital and escape could be endured[7]. They cited Buhrlen's[5] 1937 experiment in which a human subject was exposed to 17 g for four minutes in a chest to back transverse acceleration on a human centrifuge.

A. <u>Tolerance to Acceleration In Various Body Positions</u>

Ballinger [1] in 1952 subjected human volunteers to time g configurations that were more than sufficient for attaining theoretical escape velocity. A human centrifuge of 7.6 meters (25 feet) radius was used to apply transverse acceleration from front to back. Subjects were fully supine in the first series, and with their knees elevated 20°, and trunk and head elevated to provide an eye to heart distance in the vertical plane of 17.5 cm (7 inches) in the second series. Seven out of seven subjects complained of severe substernal pain and shortness of breath during two minutes and 40 seconds of exposure to 8 g in the fully supine position. The semi-recumbent position with knees and trunk slightly elevated diminished discomfort to an acceptable level at 8 g and made it possible for 2 out of 3 subjects to tolerate 10 g for two minutes and 6 seconds.

In the conventional seated position Bondurant and Clarke[3] found that transverse acceleration from front to back caused dyspnea

and chest pain, reaching tolerance limits at 8 g (See figs. 2 and 3). If the trunk is at an angle greater than 70° to the direction of acceleration, severe quasi-pleuritic, anterior chest pain limits tolerance to about 7 g. Decreasing the angle below 70° increases a positive g component with blackout at progressively lower accelerations. The best tolerances have been obtained with the subject leaning in the direction of acceleration at 65° to 70° angle. Elevating the knees until the thighs are parallel with accelerative force allows a greater displacement of blood toward the trunk, with an effect similar to an anti-g suit. Tolerance was higher than in the previously reported experiments of Ballinger (1) with legs and trunk elevated only 20°. In both these positions respiration becomes difficult above 4 g, and at 6 to 8 g tolerance time is limited by the ability of the subject to accomplish forced abdominal breathing. Petechiae of the back and anti-cubital fossae were consistent above 6 g. All subjects could describe pertinent subjective reactions immediately after the run. Most were able to make coordinated hand and arm movement before the centrifuge stopped. All were able to walk with unsteady gait within a minute after acceleration. The unsteady gait, along with dizziness, vertigo, and occasionally nausea persisted for one to five

minutes after the run.

Transverse acceleration applied from back to front, was limited by distribution of the pressure on the body against the restraining harness straps and by the hydrostatic pressure and vascular distention in the legs, congested by acceleration toward the feet. Tolerance limit was 5 g with the legs extended, due to intense calf and thigh pains. Seated upright with legs at 90° to the line of acceleration was optimal, with leg pain and dyspnea limiting endurance above 8 g.

In the positive g position, with back of seat tilted backward 13° and legs partially extended, fatigue, backache and headache limited tolerance to exposures lasting more than ten minutes to less than 4 g (See fig. 4). At 4 to 5 g blackout was frequent. Occasionally episodes of profuse sweating, pallor, nausea, tachycardia and a sensation of imminent syncope occurred without relation to magnitude or duration of positive acceleration. Weakness, dizziness, malaise and nausea often persisted several hours after these episodes.

In the negative g position, tolerance was lowest and was limited by head and eye pain.

## B. Performance During Prolonged Acceleration

Preston-Thomas and Edelberg[10] in 1955, using the same centrifuge, positioned subjects on a litter that elevated the back and head 15° from horizontal and the knees at a 60° angle for acceleration in the transverse front to back direction. Capability of subjects to exercise manual guidance control was evaluated by a wrist joy stick registering apparent vertical and horizontal components through potentiometer linkage to corresponding galvanometer dials. An oscillator with .083 cycles per second output was used to produce asynchronous, spontaneous deviations in the pointers of the two galvanometer dials. Effectiveness of corrective actions taken by the subject were evaluated from oscillograph traces during time g acceleration patterns simulating three stage rocket accelerations with peaks respectively of 8 g, 5.8 g and 5.8 g experienced within a six minute exposure. It was determined that under these conditions, 9 subjects were capable of manual control with a small loss of accuracy.

Arm and leg movements are not likely to be effective in any position above 6 g. Wrists and fingers could be moved in all positions at all g magnitudes.

C. Three Stage Accelerations to Orbital Velocity

Bondurant and Clarke[3] in 1958 reported on transverse, front to back accelerations of human volunteers on the same centrifuge. Rates of onset varied from .1 to 8 g per second, building up to peaks of 8, 10 or 12 g. After each peak, deceleration to 1.5 g was effected in 20 to 35 seconds. The succeeding acceleration was begun immediately. Each experiment consisted of successive accelerations to three instantaneous peaks of 8, 10 or 12 g. The rate of increase of acceleration that would attain more than 8,000 meters per second (18,000 mph) at peak acceleration for each stage, not counting 15-25% excess acceleration because the centrifuge could not be stopped abruptly, was applied for each three successive peaks during a run (See Fig. 1). In the series of three peaks at 12 g, the rate of increase of acceleration was 1 g per 4.5 seconds; for the series with three peaks at 10 g, the rate was 1 g per 7 seconds; and in the series with three peaks at 8 g, the rate was 1 g per 12 seconds. Tolerance limits were determined subjectively when volunteers lost peripheral vision, were unable to breathe, or felt pain of an intensity that impaired judgment or performance. Within limits thus defined, a subject would be expected to see, think,

and exercise at least finger control, although accuracy of coordination and competency of judgment remain to be evaluated. Experience with the centrifuge and motivation were appreciable factors for subjective limits.

D. Tolerance to Acceleration While Immersed

Tolerance for duration of accelerations of 6, 8, 10, and 12 g in semi-supine subjects immersed in a tank of water on the centrifuge has also been studied by Bondurant and Clarke [3]. A skin diver's valve mounted under water at chest level delivered air for respiration at a pressure equal to the hydrostatic pressure against the chest wall. For the immersed subject, a 35° angle of the trunk to the line of force was optimal. Petechiae do not occur even at 12 g and there is freedom of movement regardless of g magnitudes. Free movements of the head increase likelihood of vertigo with increasing acceleration values.

In a closed chamber referred to as the "iron maiden," mounted on the Centrifuge at the Naval Aeromedical Acceleration Laboratory at Johnsville, Pa., volunteers have been completely immersed and subjected to high accelerative force applied transversely from back to chest. One subject withstood 31 g for 5 seconds with

minor, non-disabling effects (Clark and Hardy [15]). While human tolerance to accelerative forces of space flight are ample to accomplish ascent and re-entry in a dry capsule, immersion during acceleration can approximately double tolerance limits, should a requirement arise for this protection.

3. Weightlessness in Null-Gravity

When a missile reaches a critical altitude, the earth's gravitational attraction becomes equal to the centrifugal force generated by the velocity of the missile, and it goes into orbit because it is balanced between the two opposite forces. It follows a circular orbit if the velocity is constant, but travels in an ellipse if the velocity varies, much like the changing velocity of a pendulum. This state of null-gravity causes weightlessness of masses located at the neutralization of opposite but equal forces.

Since it cannot be simulated on the ground, brief exposures to weightlessness can be obtained from free fall by parachute before air drag begins to decrease acceleration, and more usefully, by putting an aircraft through a maneuver that combines centrifugal force with free fall (Haber [16]). By flying an aircraft to sufficient height, a

climbing outside loop can be executed similar to a ballistic trajectory; weightlessness will be possible for up to 40 seconds during this trajectory in a fast jet aircraft, exactly as it would be in a space flight orbit (Campbell [17]).

In order to observe the effects of weightlessness in a large cabin space where occupants can float freely, a propeller driven transport converted into a flying laboratory is used. Because of its low flying speed, the segment of orbital flight can only be maintained for 15 seconds. For comparison, the X-15 rocket plane will be able to maintain 7 or 8 minutes of zero gravity during descent from 100 miles altitude. The 15 second weightless intervals of flight can be repeated frequently during a flight of the twin engine Convair transport; in two hours, a dozen or more weightless intervals can be experienced.

From motion picture records of these experiments, the following observations are obtained (Brown [18]):

1. Successive 15-second exposure of subjects free floating in the cabin space show that kicking or pushing away from cabin walls will propel subjects from point to point while floating in the air; the momentum of arms or legs flung vigorously in swimming motions will

propel by reaction and permit turns and rotations to be accomplished. Walking is ineffectual because of lack of friction due to weightlessness; a trained tumbler, however, is able to execute as many flips, forward or backward, as the 15-second interval will permit.

2. Locomotion by clinging to floor or ceiling with suction cups fastened to the heels of the shoes to provide friction is possible but awkward; magnets on slippers attached to the above were more effective, but not as effective as electromagnets that turn on or off to match walking movements. High pressure air bottles with a hand controlled nozzle to be used as a reaction jet proved difficult to manage because of accelerated response to thrust in any direction even for brief blasts.

3. Most subjects enjoy the sensations of weightlessness, although some who are prone to motion sickness become nauseated, particularly with abrupt rotations around the long axis of the body. The threshold is reduced in comparison with rotation in a Barany chair in the normal one g ambient.

4. While free floating in the weightless state, spatial orientation is visual, and refers to normal perception of people and objects around the subject. When the eyes are closed, there is disorientation

until they are opened again, restoring visual clues.

5. While walking inverted on the ceiling of the aircraft by use of suction cups or magnetic slippers on the shoes, the sensation of muscular orientation from having the feet on a surface takes precedence over visual orientation, and by a shift of perception, there is a feeling of walking on a floor with all surrounding objects upside down. As soon as the feet detach, visual perception again takes precedence, and abruptly people and objects appear right side up again.

6. Coordination and visually guided hand movements are accomplished with no change in effectiveness during transition from ambient gravity to weightlessness, so long as the body is anchored firmly to the seat with a belt. If the belt is loose, arm movements produce reaction and the subject pushes himself away as he reaches for something. A subject turning a wrench while weightless turns in the same direction, if he does not hold himself in place with the other hand.

Experiments with two-place jet fighter aircraft, in which the duration of weightless trajectory was as long as forty seconds revealed by motion pictures that fluids can be propelled but not poured in the weightless state, and will scatter in floating droplets

instead of being taken into the mouth and swallowed. Plastic tubes of food and drink, similar to those used for toothpaste, enable food and liquids to be transferred to the mouth, after which mastication and swallowing are accomplished normally. Peristalsis is not affected by the absence of gravity. In other experiments von Beckh [2] has demonstrated that the threshold for blackout due to acceleration of coming out of a dive will be diminished by one and a half gravities after 20-30 seconds of exposure to weightlessness. A volunteer subject was transitioned from ambient gravity to 4.5-5.0 gravities during the pull up maneuver of the aircraft, and his relaxed blackout point determined. When preceded by a 20-30 second exposure to weightlessness, only 3.0-3.5 gravities were required to produce blackout. Considering how the 6 semicircular canals and 4 utricles of human subjects respond to very slight centrifugal, tangential and coriolis accelerations with persistent oculogyral illusions in ambient earth gravity, observed by Gray [19], Graybiel, et al [20], serious problems may be encountered with rapid head movements following adaptation to persistent null-gravity in orbit. These would require subjective evaluation beyond the scope of animal experiments. The effect of re-entry into appreciable to severe accelerative force fields after prolonged sensory

adaptation to null-gravity could be acutely disorienting at a critical phase of space flight, and might, paradoxically, be more disabling than the anatomical and haemodynamic stresses of re-entry and recovery. Weightlessness still presents problems affecting human performance that elude evaluation through bioastronautical animal experiments, as well as the short duration human exposures in aircraft Keplerian trajectory experiments. A previously sleeping subject in the observer's seat, when awakened suddenly, during weightlessness, was completely disoriented until the restoration of ambient gravity. No human exposure to date has lasted long enough to permit physiological adaptation to take place. In Russian experiments with dogs during free fall in a capsule dropped from a vertical ascent missile at 131 miles, recordings of respiration, electrocardiograph and blood pressure were elevated for about 5 or 6 minutes of the free fall before becoming normal during weightlessness. In the Russian Sputnik II orbital experiment with the dog Laika, it required three times as long for vital signs to become normal in the weightless state compared to simulated rocket accelerations of ascent on a centrifuge, followed by normal earth ambient gravity. Following physiological adaptation, Laika's reactions were normal, including

conditioned reflexes for eating from an automatic feeder, for the five days that the oxygen system was able to keep her alive. This would indicate that man should be able to tolerate weightlessness and make similar adjustments for at least as long as the dog did. Proof of this awaits man's first flight into orbit. There is no other way to obtain exposures of several hours or days to weightlessness. In weightlessness, much less than customary muscular exertion will be required, with possible consequences to rest and sleep requirements. Effects on muscle tonus remain to be determined.

4. Vibration Problems

The following is a direct quotation from von Gierke(21):

Generally it is reasonable to assume that vibrations from booster engines constitute no serious hazard to man, especially since they are of only relatively short duration. They will probably be most severe when a rocketcraft shudders on the launch pad at the end of the countdown. Similarly the transverse low-frequency vibrations caused by corrections of the guidance system will probably not exceed the order of 1 g and, if necessary, will be amenable to engineering control.

The vibration problems which appear most serious at this

time are due to the transient accelerations known to occur at the sudden burnout of the rocket engine and to the possible oscillations that could occur during skip-glide re-entry. The maximum of the spectrum in this case is at 1.2 cps. This is a very unfavorable frequency range with respect to a pilot's general physiological tolerance and to vestibular disturbances and vertigo in particular. These transient phenomena in the longitudinal direction may be in the order of 5 to 8 g's.

Under unfavorable conditions, parts of the human body can be displaced more and injured earlier by exposure to such a transient acceleration than by a static acceleration of the same amplitude. It is therefore very important to know the frequency range to which man is most susceptible in order to prevent any exposure to vibrations of these frequencies or to protect against them by use of proper seats, suits, harnesses or other measures.

Man absorbs most vibratory energy from his environment in the approximate frequency range from 0.5 to 20 cps, where his built in vibration isolation capacity is least effective. The reason for this is that several mechanical resonances in the body structure occur in this frequency range. One of the most critical ones with

respect to injury is probably that of the thorax-abdomen system. For man the same type of resonance has been found during measurements on the vibration tables using accelerometers on the abdominal wall. The same resonances are excited by longitudinal and transverse vibrations. Acceleration of the table was held constant as a function of frequency. Resonance around 4 cps is also predominant for transverse vibrations. Knowledge of the impedance allows calculation of the absolute mechanical energy transmitted to the system, a quantity of extreme interest for mechanical-pathological as well as physiological effects. Magid, Coermann, et al [22], report that at 2 cps the body impedance is identical with a pure mass reactance, while at approximately 5 and 11 cps there are resonance peaks. The 5 cps resonance relates to resonant motions of the upper torso in relation to bending elasticity of the pelvis and spine; the 11 cps peak is probably due to another elasticity of the pelvis (See Fig 6).

When the supine subject is rigidly fixed to the shake table and it is vibrated with sinusoidal motions longitudinally, the resonant responses of the thorax-abdomen system can be measured. Accelerometers on the abdomen, chest circumference changes are measured with a pneumograph, and alternating air flow through the mouth was

measured with a breathing head. Simultaneous measurements of vertical vibration amplitude of the abdominal wall, circumference changes of the chest, and oscillating air volume through the open mouth show coinciding maxima between 3 and 4 cycles per second on all subjects studied. Under the influence of longitudinal as well as transverse vibrations of the torso, the abdominal mass vibrates in and out of the thoracic cage. Caudad displacement of the abdominal contents distends the abdomen and the chest circumference decreases as the diaphragm deflects downward; at the other end of the cycle, the abdomen contracts as the diaphragm moves upward and the chest expands. The resulting compression of the lungs forces air out of trachea and mouth. Restricting mobility of the abdomen or of the chest will change the resonant peak to 7 cps. Human subjects in the sitting position were subjected to severe vibrations for short durations, with abdominal and thoracic pain as limiting factors in the minimum tolerance range of 4 to 8 cps. From these findings it becomes evident that rocket craft vibrations in the range of .5 to 20 cycles per second having significant amplitudes with respect to human tolerance constitute a definite hazard. The ever increasing thrust of rocket motors requires calibration of this factor and appropriate protection from it

for astronauts. Direction of vibration, posture and support of the body, as well as protective harnesses will become of extreme importance.

5. Re-Entry Accelerations

It is reported that the 4.5 ton orbiting space vehicle containing biological specimens launched by the Russians on August 19, 1960, accomplished re-entry into the atmosphere and successful ejection and parachute landing of the life support capsule without exceeding 10 g deceleration during re-entry. This bears out calculations and re-entry trajectories of Chapman(23), Phillips(24), and Tobak, et al(25) used by Clarke, et al(26), in evaluating human response to rearward facing re-entry accelerations. Four human subjects were able to tolerate a three-minute simulated re-entry acceleration from escape velocity on the human centrifuge, attaining 16.5 g (Fig. 7). This curve incloses three calculated re-entry profiles from escape velocity, having maxima ranging from 9 to 15 g. Subjects were supported in a nylon net couch simulating the seated, rearward facing body position for re-entry.

On the Navy Centrifuge at Johnsville, Pennsylvania, a peak of 25 g during a 40 second duration was sustained by human volunteers

placed in the same body configuration on a molded plastic couch similar to the Mercury Capsule body support system.

Indication of survival limits for prolonged acceleration on the centrifuge for high accelerations are reported by Stoll and Mosely[14] who found that chimpanzees in the fully supine position could endure centrifuge accelerations to 40 g for 60 seconds, although vascular damage was encountered at 40 g in the semi-supine and semi-prone positions.

Until re-entry decelerations can be either programmed or directly controlled by the space pilot to not exceed 4 g, ground control of re-entry, or automatic programming following initiation by either the pilot or ground control will be required during exposure to forces that exceed human limits for eye-hand coordination and reliable cerebration. Beyond that, survivability is still assured by human tolerance limits determined in human centrifuge experiments.

6. Recovery and Landing Decelerations

Abrupt linear forces such as might be encountered in opening shocks of recovery parachutes following re-entry from space flight or during impact of landing on hard surfaces have been investigated by the author [12, 13] to the limits of voluntary human tolerance; and

with anesthetized chimpanzee subjects, to injury limits and to lethal limits. A rocket powered sled mounted on rails holding the subject and instrumentation was accelerated to sonic velocities in five seconds and decelerated by water inertia to a stop in less than .4 seconds in distances as short as 50 meters (164 feet) from velocities of 300 meters per second (984 feet per second) in determining injurious and lethal limits for chimpanzees seated facing forward. Injuries and death were the result of pulmonary and cardiovascular trauma (See Fig. 5). Survival limit for transverse decelerative force applied from front to back in lightly anesthetized chimpanzees optimally restrained by nylon webbing was reached at 237 g peak with 11,250 g per second rate of onset and .35 second total exposure duration. Persistent injury was found above 5000 g per second rate of onset, 135 g peak and .35 second duration, although transient injury effects were observed at 60 g at higher than 5000 g per second rate of onset in the transverse direction.

Decelerations of less than 40 g rate of onset lower than 600 g per second and total duration below .2 seconds, comparable to decelerating from 194 Kilometers per hour (120 miles an hour) in 5.8 meters (19 feet) can be survived with no persistent injury by subjects

restrained adequately while seated facing either forward or backward to the direction of linear force.

## DISCUSSION

The "G" spectrum of human tolerance and adaptability to vibrations, oscillations, impacts and sustained accelerations covers all survivable space flight plans. It has been presented with respect to the procrustean limitations of weight and space imposed by the minimum life support capsule for one man on a one day orbital flight; it requires no elaboration to interpolate application to a down range manned ballistic flight of five thousand miles or more, already successfully proven with small primates, which survived unharmed; lunar rocket flights will be accomplished with soft landings staying in the bounds of human tolerance for retarding rocket deceleration and landing impacts, as specific design to meet human requirements takes the place of crowding and squeezing the man to fit the limitations of available systems.

The space pilot will enter his unquestioned domain in flights of less than orbital velocity within the altitude range between the upper limit of aerodynamic flight and the lower limit for maintained orbital

flight, the area between 40 and 200 kilometers (25-125 miles) where skipflight by bombers and transports described by Sanger-Brett during World War II, is possible. Some future breakthrough in propulsion may make possible sustained flight on thrust lift by rocket motors at any chosen vertical and horizontal velocities. The same acceleration limits prevailing for jet aircraft crews must be adhered to in this space flight regime, with the addition of precautions regarding sensory illusions from maneuvers in subgravity and null-gravity conditions.

It is entirely possible that the most vexing problems of space flight will occur at the low end of the "G" spectrum, due to impaired perception and illusions of motion. The accumulative fatigue from exposure to repeated high accelerations in skipflight may also be a factor to be reckoned with.

The challenge of rising above these limitations is no less than the challenge of achieving space flight. To conquer space, man must first conquer his own limitations.

The "G" Spectrum In Space Flight Dynamics--
Colonel John P. Stapp

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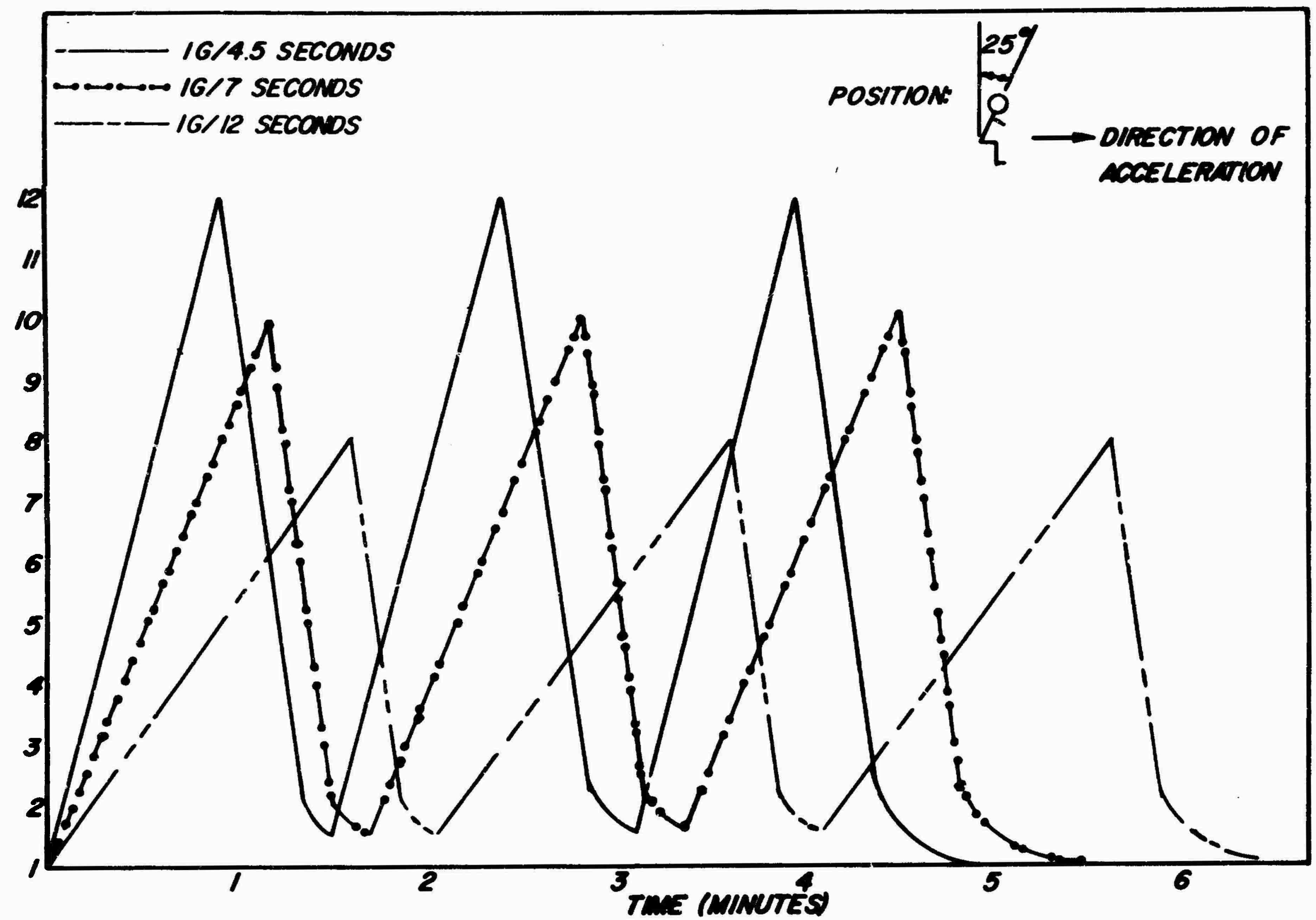
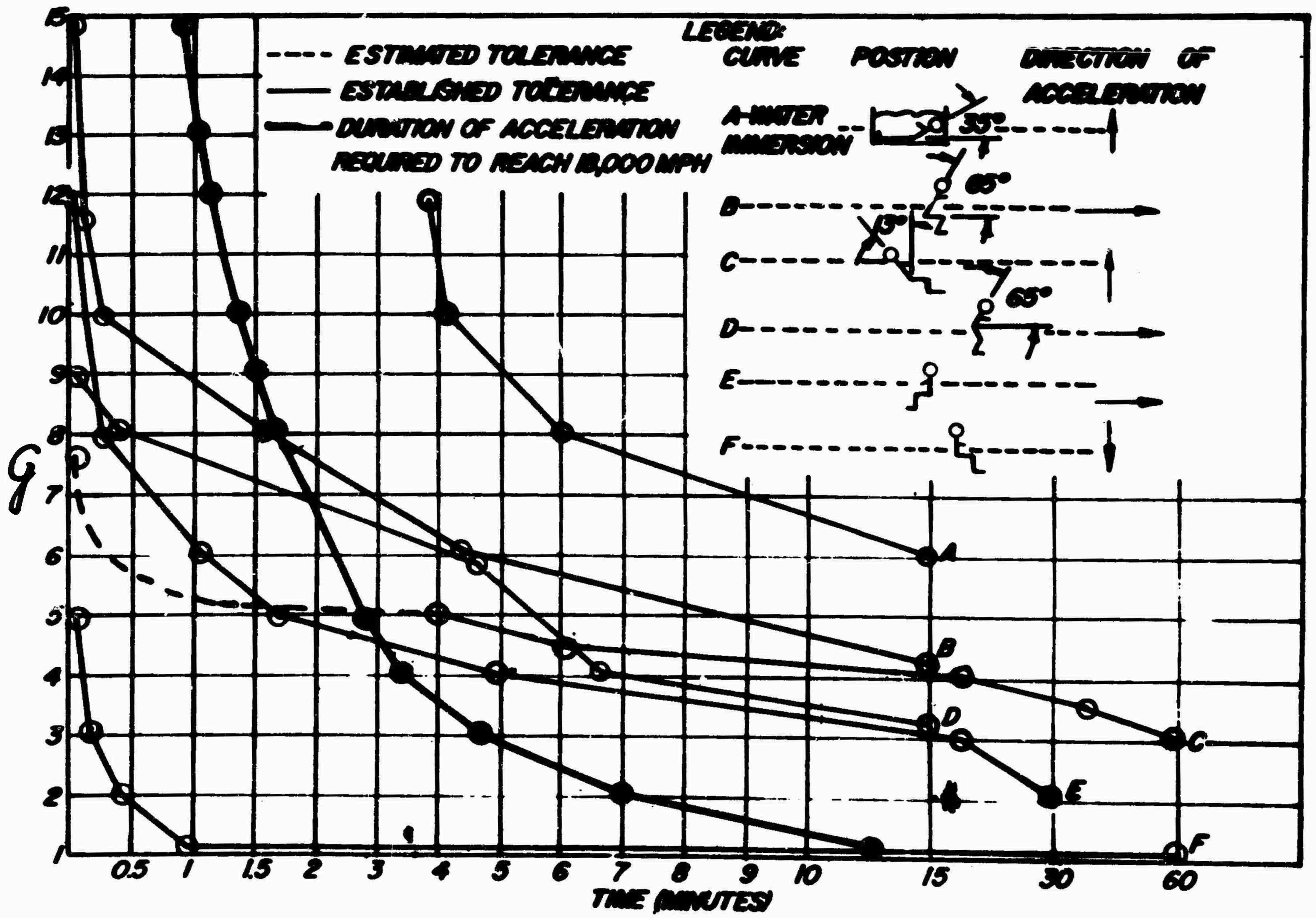



SOME 3 STAGE ROCKET ACCELERATION PATTERNS SUFFICIENT TO EXCEED ORBITAL VELOCITY WHICH ARE TOLERABLE TO MAN

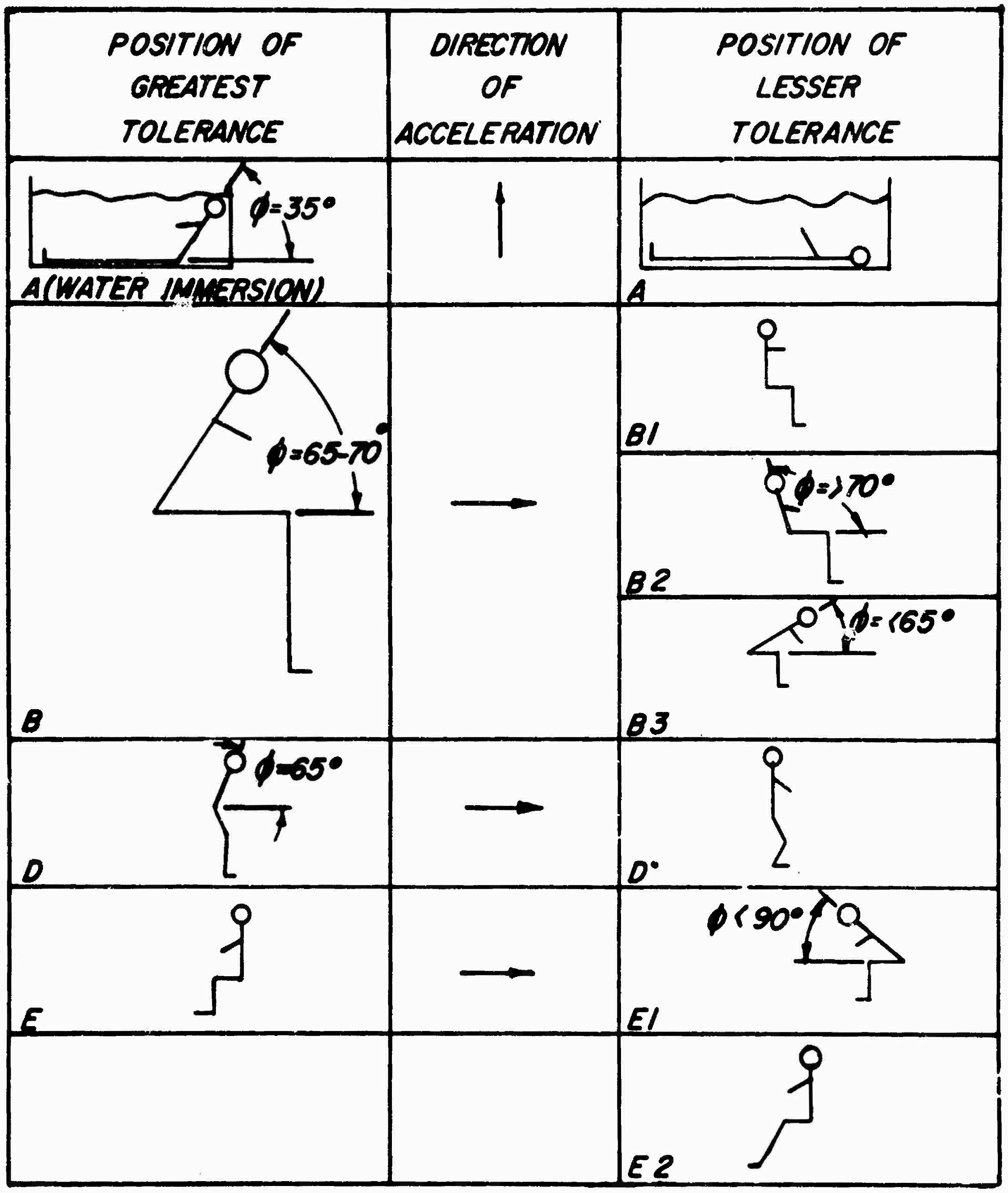
Figure 1




THE DURATION OF TOLERANCE TO ACCELERATION

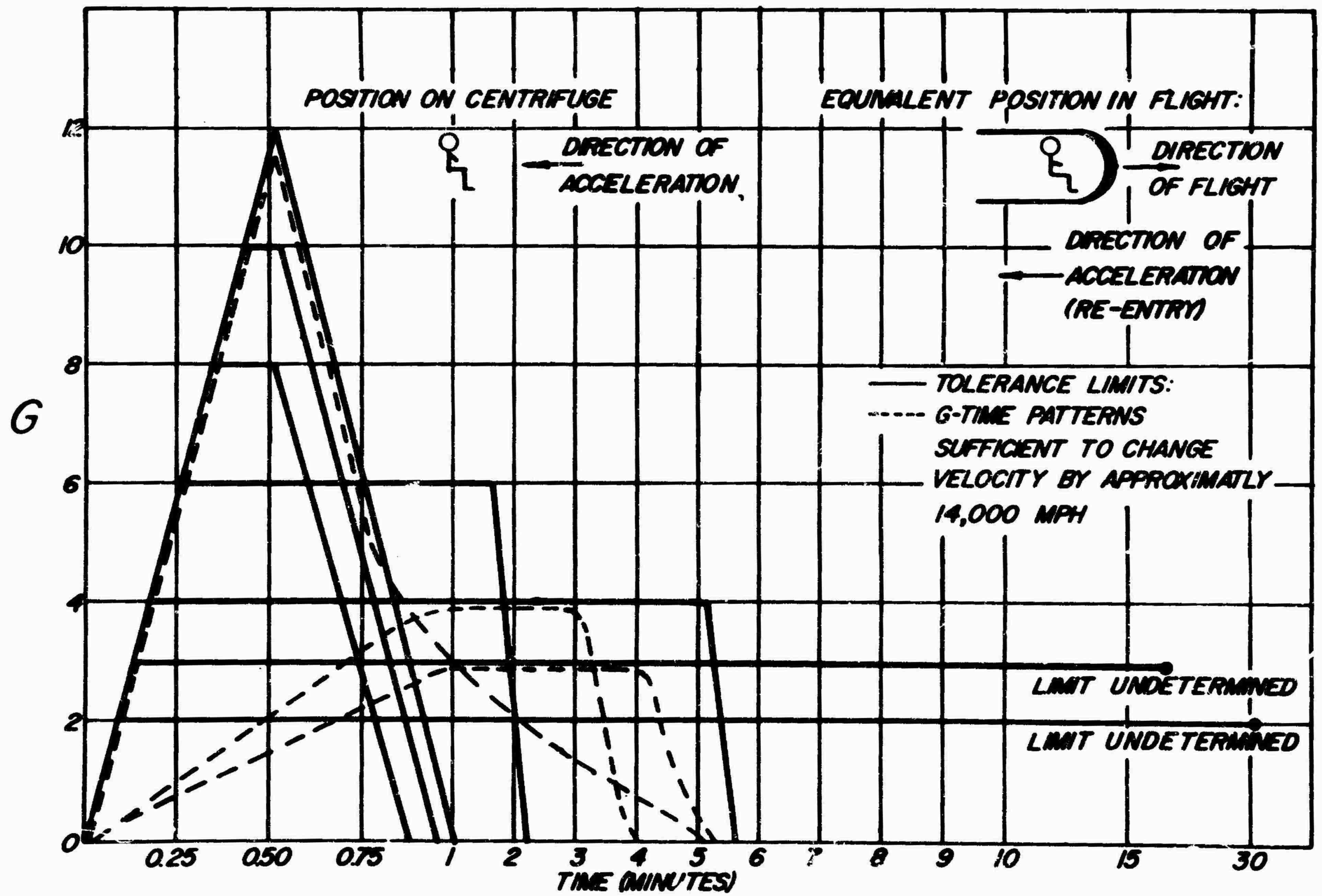
Figure 2

12



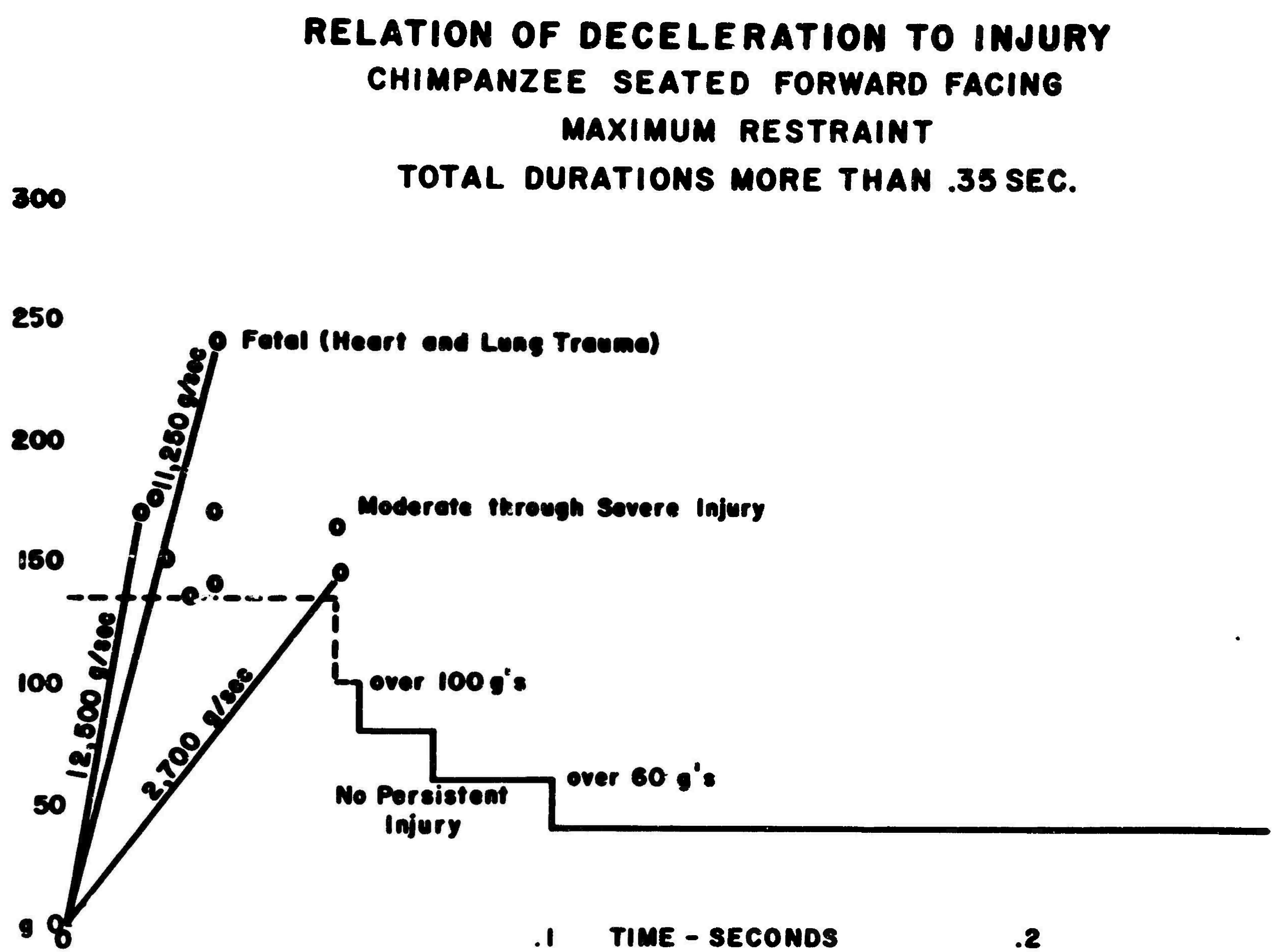

VARIATIONS IN POSITION WHICH DECREASE TOLERANCE TO ACCELERATION (SEE TEXT)

Figure 3



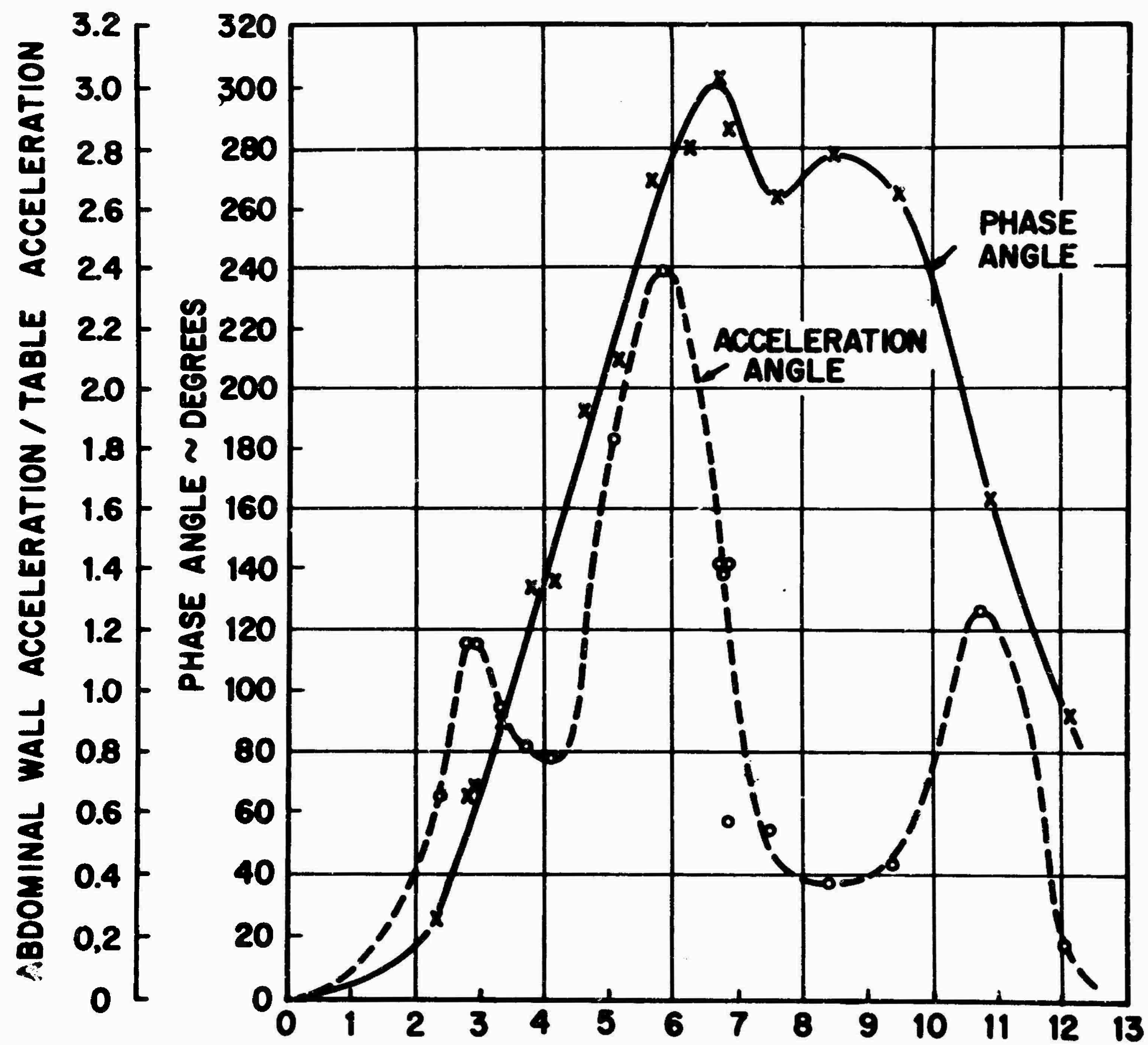

TOLERANCE OF SEATED, FORWARD FACING SUBJECT TO DECELERATION IN LINE OF FLIGHT (RE-ENTRY)

Figure 4



RELATION OF DECELERATION TO INJURY
CHIMPANZEE SEATED FORWARD FACING
MAXIMUM RESTRAINT
TOTAL DURATIONS MORE THAN .35 SEC.
300
250
200
150
100
50
g
0
Fatal (Heart and Lung Trauma)
11,250 g/sec
12,500 g/sec
2,700 g/sec
Moderate through Severe Injury
over 100 g's
over 60 g's
No Persistent Injury
.1
TIME - SECONDS
.2


Figure 5



ABDOMINAL WALL ACCELERATION / TABLE ACCELERATION
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0,2
0
PHASE ANGLE ~ DEGREES
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
PHASE
ANGLE
ACCELERATION
ANGLE
0 1 2 3 4 5 6 7 8 9 10 11 12 13
FREQUENCY IN CPS


Figure 6

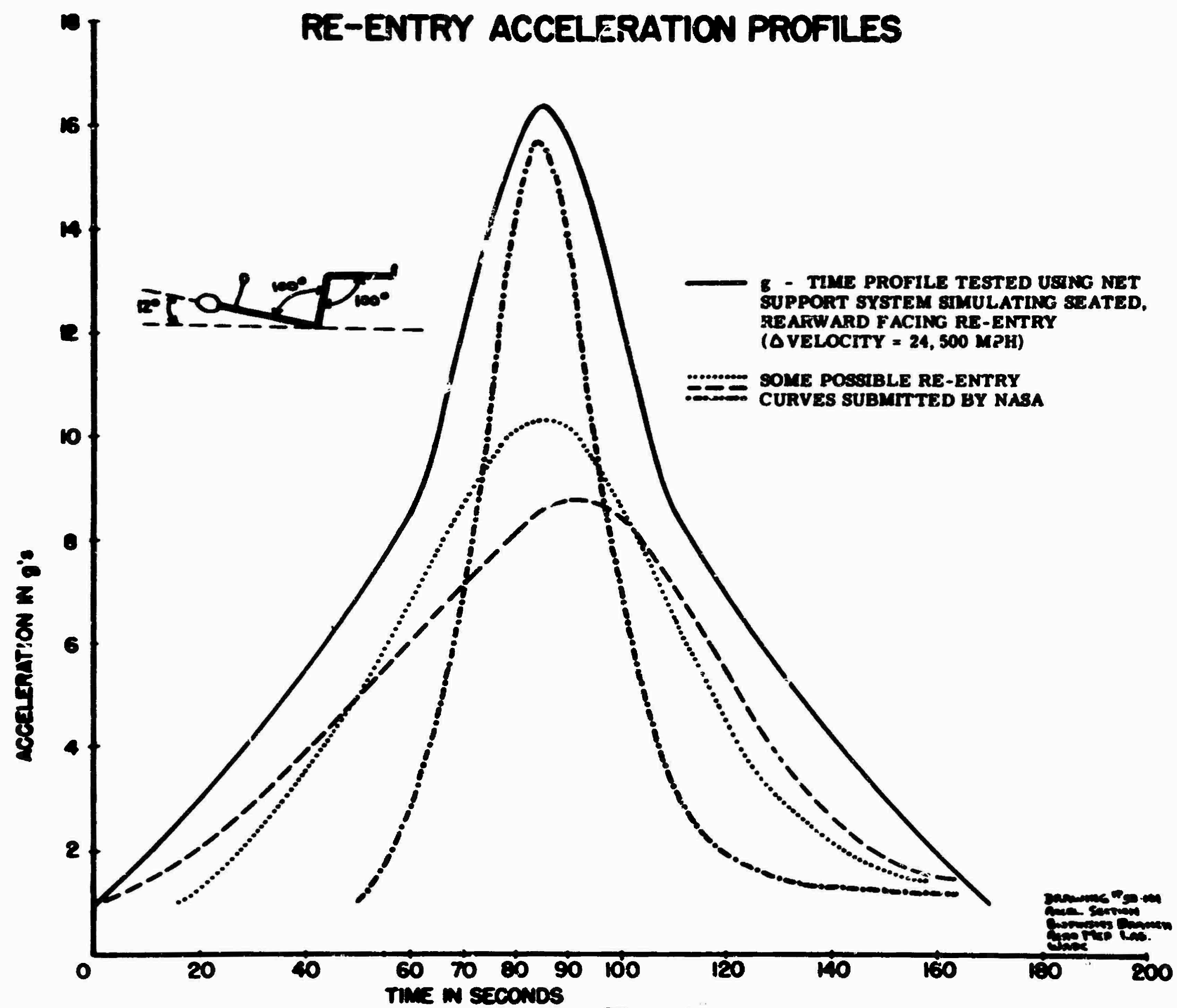

RE-ENTRY ACCELERATION PROFILES
ACCELERATION IN g's
TIME IN SECONDS
0
20
40
60
70
80
90
100
120
140
160
180
200
2
4
6
8
10
12
14
16
18
12°
100°
100°
g - TIME PROFILE TESTED USING NET SUPPORT SYSTEM SIMULATING SEATED, REARWARD FACING RE-ENTRY (Δ VELOCITY = 24,500 MPH)
SOME POSSIBLE RE-ENTRY CURVES SUBMITTED BY NASA

Figure 7

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# LECTURES IN AEROSPACE MEDICINE

## SEALED CABIN EXPERIMENTATION


Presented By

B. E. Welch, Ph.D.

Chief, Space Ecology Branch

School of Aviation Medicine

# SEALED CABIN EXPERIMENTATION

by

B. E. Welch, Ph.D.

Prior to the time that man goes into space, much background work and laboratory testing must be completed. A tremendous number of variables must be identified and their separate and combined impacts on the biological portion of the vehicle system assessed. These variables range from the physical ones such as cabin altitude and gas composition through physiological parameters and logistics to the emotional aspects of isolation, confinement and danger. Some of these variables can be studied separately and in various combinations in ground-based space cabin simulators, which forms the basis for this paper - a discussion of the sealed cabin experimentation being conducted at the School of Aviation Medicine.

When one studies man in these rather unique situations, one is still concerned, basically, with a study of man's physiological, biochemical, medical, physical and mental responses to nothing more than altered environments. The fact that the term "space" is attached to the work might indicate that this is an exotic area of research, but this is not true. Man has rather narrow environmental limits for survival and even more narrow limits for effective performance. Some of these limits are fairly well fixed, others somewhat more fluid. Whether fixed or fluid, all have a

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NOTE: This manuscript reflects the views of the author and should not be considered official Air Force policy.

certain amount of background data that can be utilized in direct application to the problems of man in the sealed cabin situation. It is essential, therefore, that we make full utilization of these background data and design experiments that will provide the information needed to confirm and supplement these data.

The purpose of this paper is to describe the experimental device being used for such research here at the School of Aviation Medicine, outline the environmental parameters studied to date and present some of the data that have been gathered in a preliminary experiment.

Two flights have been completed in the two-man simulator. The first was of 14 days duration and was designed primarily as an equipment check flight. The second flight lasted 30 days, 8 hours and 21 minutes and was planned as a final equipment check-out flight in addition to obtaining medical, physiological, biochemical, psychological and psychiatric data. It is the latter flight that will be discussed in this paper.

DESCRIPTION OF THE SIMULATOR

The two-man space cabin simulator is a hermetically sealed cabin containing all the necessary environmental control and life support equipment on-board, with the exception of the heat exchanger and power supply. It was not designed as an operational vehicle, but as a research tool. In this capacity, it provides us with a large amount of data relevant to the problems of maintaining man in space. An artist's conception of this simulator is shown in Figure 1. Basically, the simulator is an elliptical shaped, steel cylinder. It is 12 feet long, 8 feet high and 5 feet wide and has a total bound volume of some 380 cubic feet. The system was

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designed for control of pressure, oxygen partial pressure, carbon dioxide partial pressure, temperature and relative humidity within the range and degree of accuracy shown in Table I. Liquid oxygen is used for an oxygen source and baralyme is currently used as a carbon dioxide absorber. Temperature and humidity are controlled by the use of cooling coils and reheaters. At a 10 psi pressure differential (28,500 feet altitude), the leak rate of ambient gases into the simulator produces a pressure change of 2.4 mm Hg per 24 hour period. If this pressure change is converted to a volume change, it amounts to approximately 1 to 1.3 liters of ambient gas leaking in per hour, depending upon the exact free air space within the chamber.

The simulator is divided roughly into two separate areas - the rest area and work area. The rest area is used for waste disposal, water purification, oxygen storage, food storage, water storage, work table and sleeping. The work area (Figure 2) is utilized as the control center of the vehicle. The left side of the control panel contains the psychomotor performance equipment and is described in detail by Hartman (1). The right side of the panel contains the environmental system controls, transfer switches, indicator lights and analyzer calibration equipment.

The outside monitor console (Figure 3) houses the primary indicators, over-riding controls, recording devices and the necessary monitoring equipment including closed circuit television. With this brief introduction of the simulator, let us now turn to the various parameters studied during this flight.

## ENVIRONMENTAL DATA

The daily averages of the environmental parameters are shown in Figure 4. The total pressure in the cabin was maintained at an average of 383 mm Hg with a minimum of 380 mm Hg and a maximum of 385.5 mm Hg. The partial pressure of oxygen was maintained at 149.5 mm Hg with a minimum of 144.5 mm Hg at the end of 30 days to a maximum of 164 mm Hg at the eleventh day. Except for this one peak, the oxygen partial pressure was very constant. The partial pressure of carbon dioxide rose in a more or less linear fashion to a peak of 10 mm at the end of the twenty-second day of the flight. At that time, a baffle plate in the absorber system was removed, allowing a greater air flow through the baralyme beds. This resulted in a fairly rapid drop to some 3 mm, with an apparent stabilization around this point. Cabin temperature average 22.5°C with a minimum of 21.25°C and a maximum of 24.5°C. The maximum point occurred when the temperature control system was turned off for repair of a circulating pump. The relative humidity data indicates a high of 30% and a low of 10%, with an average of 19%. These humidity data are open to question, however, since comparison of the cabin indicator with a sling psychrometer at the end of the flight showed a discrepancy of some 30-40%.

## NUTRITION

Dehydrated, pre-cooked foods obtained from the Quartermaster Food and Container Institute, Chicago, Illinois, made up the bulk of the diet. There were a few items such as prefried bacon, cookies and candy that were not in a dehydrated form. A listing of some representative food

items is shown in Table II. These foods require only the addition of either hot or cold water, depending on the food item, for reconstitution. After soaking for a few minutes, they are ready for consumption.

Caloric intake was determined by providing weighed food packages of known caloric composition. The subjects were allowed to consume the food _ad lib_ with the requirement that they consume all the food in the package once it had been opened. Food consumed was then reported on a daily basis.

A summary of the caloric intake data is shown in Table III. The raw intake values of 1406 and 1667 Kcal/man/day are undoubtedly low due to an observed weight loss of 3.64 kg and 2.39 kg in Subjects A and B, respectively. Since sufficient data are not available to adequately characterize this weight loss, a value of 6.0 Kcal/gm (2) has been used to correct, tentatively, the caloric intake for weight loss. This yields an approximate caloric intake 2134 and 2145 Kcal/day for the two subjects. When expressed on a body weight basis, the values are 31.14 and 29.96 Kcal/kg body weight (corrected for weight loss) for Subjects A and B, respectively. In other words, when compared to intakes (3) for moderate work (48 Kcal/kg) and heavy work (61 Kcal/kg), this can be classed as sedentary or very light work. This level of energy intake probably represents the maximum that will be encountered in space vehicles for some time to come unless the emotional factors play a more deciding role than is currently anticipated.

The percentage of calories derived from carbohydrate, fat and protein was 56.8%, 25.0% and 18.2%, respectively, for Subject A and 52.0%, 30.7% and 17.3%, respectively, for Subject B.

## WATER

Water requirements were met by both stored supplies on board at the start of the flight and by water recycled during the flight. The recycled water was purified by a vacuum distillation apparatus shown schematically in Figure 5. Water from all sources (urine, wash water and water condensed from the cabin atmosphere) was pooled in the pretreat tank. It was treated with acid to reduce the pH to 2-3 and then passed through a filter. From the filter, the urine passes to the still where the distillation was accomplished at 35-37°C. The gaseous phase was passed through activated carbon maintained at approximately 45°C and then condensed. The condensate was checked for purity by making tests on each batch of water. Odor, appearance, ammonia content and absorption spectra in the range of 220 to 340 mu were used as criteria of acceptability. The men derived some 45 to 50% of their water supply from the water purification system.

A summary of the water data is presented in Table IV. The average daily requirement was 1601 and 1974 gms/day for Subjects A and B, respectively. This includes that amount of water utilized for personal hygiene as well as that consumed as liquid and used to rehydrate food. The actual water intake was 1451 and 1745 gms/day. The water excreted by way of the kidney and in fecal material was found to be 1114 gms/day for Subject A and 970 gms/day for Subject B.

The amount of water lost by way of the lungs and skin as insensible perspiration is unknown. Kuno (4) has estimated this to be on the order of 900 ml/man/day. This estimate, however, is based on a sea-level

condition. The influence of altitude on this insensible loss is not clearly understood, however, making the use of the 900 ml/man/day figure, in this particular situation, open to question. Total body water measurements by the antipyrine method indicated a water loss in both individuals. However, the insensible loss in Subject A could not have approached the 900 ml/man/day figure, since this would have resulted in an approximate 17 liter loss of total body water during the 30 day period. Such a loss from a 37 to 40 liter fluid pool would certainly not be tolerated too well by the human organism.

OXYGEN CONSUMPTION - CARBON DIOXIDE PRODUCTION

Oxygen requirements can be estimated from caloric intake. If one assumes a value of 4.825 Kcal/liter oxygen required, an average daily oxygen requirement of approximately 460 liters/man or approximately 1.45 lbs/man/day is indicated. The corrected caloric intake values of 2134 and 2145 Kcal/day were used in this calculation. This requirement can be examined also in terms of its relationship to the liquid oxygen system installed in the cabin. This is shown in Figure 6.

The flight was started with a total of 45.9 liters of liquid oxygen on board in two oxygen converters. Each converter is designed to "boil-off" 0.8 liters of oxygen/day, which yields the straight line labelled "predicted." The observed "boil-off" varied considerably from the predicted value during the early stages of flight, but agreed very closely during the latter third of the experiment. Part of this variation is probably due to discrepancy in power supply regulation going to the system. At any rate, the main point of interest is the oxygen requirement expressed in terms of liters of liquid oxygen. It is apparent that oxygen is being evaporated

from the converter at a faster rate than the occupants can use it for themselves. This does not mean that this excess oxygen is completely wasted, however, since at least a portion of it was used in the maintenance of the total cabin pressure. If liquid oxygen converters are to be of great value to us in space, however, the requirement rate should certainly exceed the "boil-off".

Carbon dioxide production can be further estimated from the oxygen requirement if one knows or assumes the respiratory quotient (R.Q.). An R. Q. of 0.85 has been assumed in this situation, which yields a value of 390 liters carbon dioxide produced. This volume is equivalent to approximately 1.53 lbs. of carbon dioxide/man/day being produced. A total of 500 lbs. of carbon dioxide absorbent baralyme was included in the cabin to absorb the carbon dioxide. This amount was obviously in excess, although it is difficult to say precisely to what extent.

IN-FLIGHT PHYSIOLOGICAL MEASURES

During the course of the experiment, data were collected daily on body temperature, pulse rate, respiration rate and blood pressures. Body temperature was taken orally every hour that the men were awake or not occupied with a maintenance problem. This resulted in a total of some 15 measurements per man per day. These individual measurements were then averaged for expression on a per day basis. Pulse rate and respiration rate were recorded several times during a two-hour period in the afternoon by means of a electrocardiograph and a pneumotacograph. Blood pressures were recorded every morning prior to the first meal.

These data are shown in Figure 7. For purposes of statistical analyses, these data were grouped into ten periods of three days each. Statistical significance was then determined between these ten periods. Body temperature decreased significantly ($p < 0.05$) in the middle portion of the flight in the case of Subject B. Pulse rate was not significantly altered in either of the men. Respiration rate declined significantly ($p < 0.05$) during the course of the experiment for both individuals. Systolic pressure showed a significant decrease ($p < 0.01$) for Subject B but not for Subject A. The diastolic pressures for both men decreased significantly at the 0.05 level.

It is of interest to note that the findings in regard to the blood pressure data are in agreement with the data of Graveline and Balke (5) who reported a gradual decrease in both systolic and diastolic pressure during the course of a seven-day water immersion study. They did not observe any consistent alterations in body temperature, pulse rate and respiration rate, however. It is rather difficult at this time to attach too much significance to these particular findings, since many variables such as the amount of physical work required of the subjects could have a great influence on the results. However, when one examines these data in view of observed cardiovascular changes following the flight, the blood pressure decrement assumes more importance.

PRE AND POST-FLIGHT PHYSIOLOGIC MEASURES

Exhaustive physical, hematological, psychological and psychiatric examinations were conducted prior to the start of the flight and again immediately following the flight. The psychological and psychiatric

examinations will not be reported in this paper. A portion of the psychological data has been reported by Hartman (1), however.

The physical examinations included measurements of work capacity and orthostatic tolerance, pulmonary function studies, audiological check and dental and ophthalmological observations. The hematological studies included hemoglobin, hematocrit, white blood cell count, differential count, red blood cell count, sodium, potassium, chloride, carbon dioxide, phosphorous, blood urea nitrogen, cholesterol, phospholipids and protein bound iodine. Urinalysis studies included albumin, sugar, specific gravity and bacteria.

WORK CAPACITY

Work capacity was measured by the use of the treadmill as previously described by Balke (6). In this test, the treadmill is operated at 3.3 mph and the angle of inclination is increased 1% (approximately 3/4°) each minute after the first minute. The test is terminated when the pulse rate reaches 180 beats per minute.

The pre and post-flight data for both subjects is shown in Figure 8. The total time on the treadmill was decreased from 16 minutes to 12 minutes for Subject A and from 15 minutes to 10 minutes for Subject B. The systolic blood pressures measured during work did not vary much between the pre- and post-flight tests. In Subject B, systolic pressure was some 5 to 10 mm Hg higher between the second and tenth minute of the test as compared with pre-flight tests. Diastolic pressures were decreased in this same individual. This agrees with the observations of Balke (6) who found that blood pressure

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measured during work was not significantly affected by four weeks of bed-rest. Pulse rate data obtained during this work capacity test showed a higher pulse rate at a given work load after the flight than before the flight. This is also typical of the effects of bed rest and also of the effects of physical fatigue (7).

It is of interest to note that the effects of four weeks bed-rest (6) produced a decrement of only two minutes (from 18 to 16) in work capacity whereas the equivalent time period in the simulator produced a 25% to 30% decrement and the seven day hypodynamic experiment of Graveline and Balke (5) produced a 53% decrement (from 15 to 8 minutes). Obviously, the hypodynamic situation produced in the simulator has drastically altered the capability of the cardiovascular system to meet a given stress with the same ease as before the exposure.

ORTHOSTATIC TOLERANCE

Orthostatic tolerance was determined on the tilt table before and after the flight by rotating the subjects from a horizontal position to a vertical position and measuring blood pressure every minute for seven minutes in the vertical or passive standing position. A summary of the blood pressure, pulse pressure and heart rate data is shown in Table V.

Both subjects had a normal control electrocardiogram during orthostasis although one subject did have minor T wave variations of a physiological nature. These T wave variations were unchanged at the post-flight testing period. The other individual (Subject A) showed a diminution of the T wave amplitude in the limb leads and lateral precordial leads at the end of the flight.

In general, the orthostatic tolerance of these subjects was not greatly affected by the 30-day flight in the simulator. While Subject B did have a decrease in pulse pressure during orthostasis after the flight, it cannot be compared to the severe drop in pulse pressure (absolute value of 4 to 6 mm Hg) reported in the hypodynamic study (5).

## PULMONARY FUNCTION

The pulmonary function studies consisted of measurements of vital capacity, timed vital capacity and maximum breathing capacity. Pulmonary function parameters were virtually unaffected. Subject A had a decrease in vital capacity of 530 cc (from 5180 to 4650) when measured at the end of the flight. Maximum breathing capacity also dropped from a pre-value of 251 liters/min to 188 liters/min. These values are still within normal limits, however. Subject B had a very slight drop in vital capacity with an increase in maximum breathing capacity.

## AUDIOLOGY

An audiological examination was performed on each subject before and after the flight to determine if exposure to a constant overall noise level of 83 decibels in the frequency range 20 to 10,000 cycles per second for the 30-day period would have an affect on hearing acuity. Neither of the individuals showed a decrease in acuity.

## OTHER EXAMINATIONS

Other tests performed included dental and ophthalmological observations which indicated that there were no adverse effects from exposure to this simulator situation. Hematological findings and biochemical

observations were essentially unchanged. There was an alteration in the ratio of polymorphonuclear cells to lymphocytic cells. The significance of this observation is not yet clear. A marked decrease (206 to 133 mg %) in cholesterol in Subject A and an approximate 35% to 50% reduction in phospholipids characterize the major changes in the biochemical area. These latter alterations probably reflect the relatively low fat diet being consumed.

Electrocardiographic studies were normal in one subject at all times studied; however, the other subject showed persistent changes in electrocardiographic response to the Master's two-step and Valsalva maneuvers following the flight. These changes (a lengthening of conduction time and premature contractions) were present up to three weeks after the end of the flight but had reverted to normal before the two-month follow-up examination. While no definite conclusions are possible, these findings indicate changes in myocardial irritability and activity occurred and persisted.

SUMMARY

It was the desire of the author that this paper would provide the reader with some concept of the breadth of the program studying the problems of man in the space cabin environment. Obviously, we have not touched on all the problem areas nor have discussed in great detail those areas mentioned. The data presented can only be considered as preliminary data obtained from two subjects. Results can be presented, but sweeping conclusions must, of necessity, await the arrival of adequate

proof in the form of repeat experiments. Time will provide this. In the interim, it can be stated that nothing was observed that indicated man could not go into a space cabin environment and perform effectively - at least for 30 days, 8 hours and 21 minutes.


## ACKNOWLEDGEMENT

The author wishes to acknowledge the assistance of many people in the various Departments of the School of Aviation Medicine for their help in obtaining much of the data reported herein; in particular, the work of TSgt William W. Henderson and the simulator technicians he supervises, who contributed greatly to the success of the experiment. Last, but not least, sincere appreciation must be given to those two individuals who gave much of their time and stamina by serving as simulator crew members for 30 days, 8 hours and 21 minutes.

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TABLE I

DESIGN RANGE AND DEGREE OF ACCURACY IN

ENVIRONMENTAL CONTROL SYSTEMS

| Variable | Range | Variation |
|---|---|---|
| Total Pressure, mm Hg | 200 - Ambient | $\pm 5$ |
| Oxygen Partial Pressure, mm Hg | 10 - 400 | $\pm 3$ |
| Carbon Dioxide Partial Pressure, mm Hg | 0 - 80 | — |
| Temperature, $^{o}F$ | 60 - 80 | $\pm 1$ |
| Relative Humidity, % | 40 - 70 | $\pm 2$ |

TABLE II

TYPICAL DEHYDRATED FOOD ITEMS

| | |
|---|---|
| Pork Chops | Peas |
| Chicken and Rice | Carrots and Peas |
| Cubed Steak | Green Beans |
| Swiss Steak | Grapefruit-Orange Juice |
| Sliced Roast Beef and Gravy | Peaches |
| Fish Patties | Fruit Cocktail |
| Roast Pork | Pineapple |
| Oatmeal | Chocolate Pudding |
| Mashed Potatoes | Chicken and Rice Soup |
| Buttered Rice | Cocoa |
| Carrots | Milk |

TABLE III

SUMMARY OF CALORIC INTAKE DATA

| | Initial Weight (kg) | Weight Loss (kg) | Caloric* Equivalent, Total (Kcal) | Caloric Equivalent, Daily (Kcal) | Measured Intake (Kcal) | Corrected Intake (Kcal) | Kcal/kg (Uncorrected) | Kcal/Kg) (Corrected) |
|---|---|---|---|---|---|---|---|---|
| Subject A | 68.52 | 3.64 | 21,840 | 728 | 1406 | 2134 | 20.52 | 31.14 |
| Subject B | 71.59 | 2.39 | 14,340 | 478 | 1667 | 2145 | 23.28 | 29.96 |

*Assuming 6.0 Kcal/gm body weight loss

TABLE IV

SUMMARY OF WATER DATA

| | Subject A | Subject B |
|---|---|---|
| Water Used (gm/day) | 1601 | 1974 |
| In Liquids | 972 | 1135 |
| Food Rehydration | 479 | 610 |
| Wash Water | 150 | 229 |
| Water Intake (gm/day) | 1451 | 1745 |
| Water Excreted (gm/day) | 1114 | 970 |
| Urine | 1059 | 902 |
| Feces* | 55 | 68 |
| Insensible and Sensible Water Loss** | ?? | ?? |

*Calculated from weight of feces with the assumption that fecal material is 80% water.

**Not determined. Kuno (4) has estimated this to be on the order of 900 ml/man/day. The influence of altitude is not clearly defined, however.

TABLE V

SUMMARY OF ORTHOSTATIC TOLERANCE DATA

| | SUBJECT A | | | | SUBJECT B | | | |
|---|---|---|---|---|---|---|---|---|
| | PRE | | POST | | PRE | | POST | |
| | BP | P | BP | P | BP | P | BP | P |
| Baseline | | | | | | | | |
| 5 Min. | 120/76 | 62 | 122/80 | 75 | 114/72 | 58 | 104/72 | 84 |
| 90° Tilt | | | | | | | | |
| 1 Min. | 120/78 | 79 | 118/84 | 88 | 112/78 | 69 | 108/98 | 88 |
| 2 Min. | 118/80 | 80 | 124/84 | 95 | 110/76 | 63 | 112/84 | 93 |
| 3 Min. | 124/82 | 83 | 122/80 | 88 | 116/80 | 75 | 112/99 | 96 |
| 4 Min. | 118/80 | 64 | 120/84 | 94 | 118/76 | 73 | 99/78 | 97 |
| 5 Min. | 122/80 | 85 | 126/86 | 101 | 118/78 | 77 | —— | 94 |
| 6 Min. | 122/82 | 74 | 112/80 | 99 | 116/80 | 70 | 104/82 | 82 |
| 7 Min. | 120/84 | 93 | 122/82 | 95 | 118/80 | 75 | 104/76 | 103 |

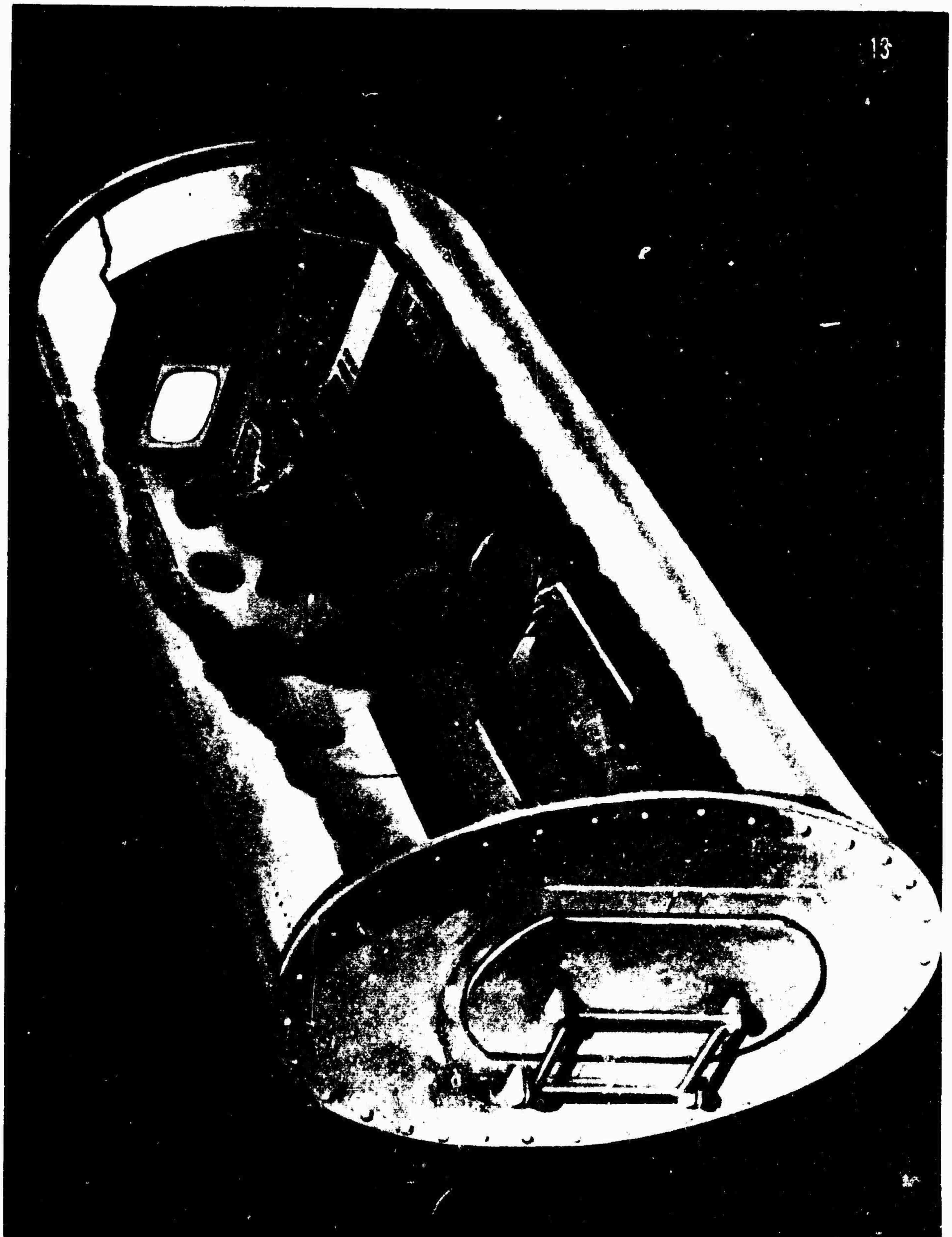


Figure 1. Artist's Conception of Two-Man Simulator

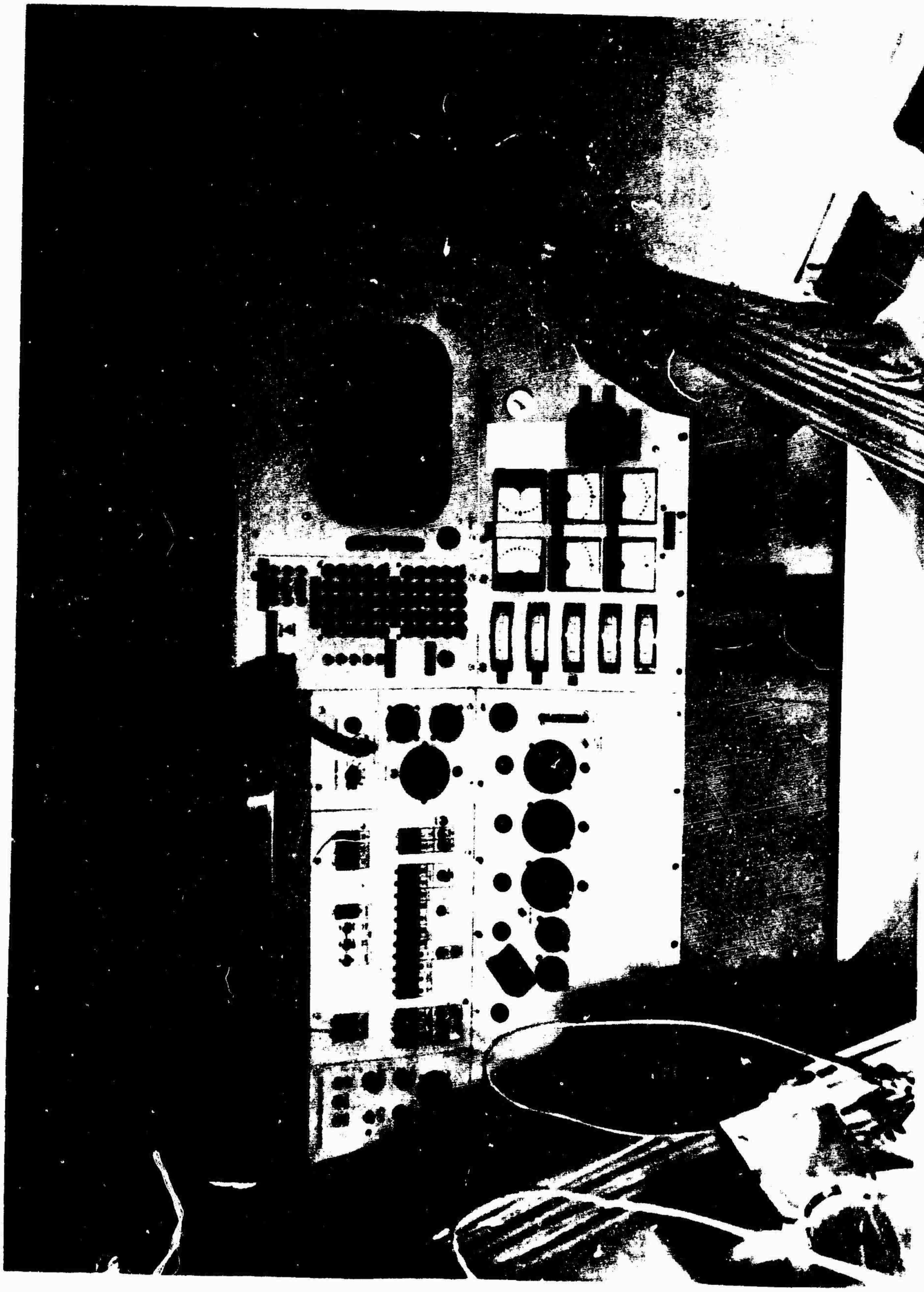

Figure 2. Close-up View of Work Area of Two-Man Simulator

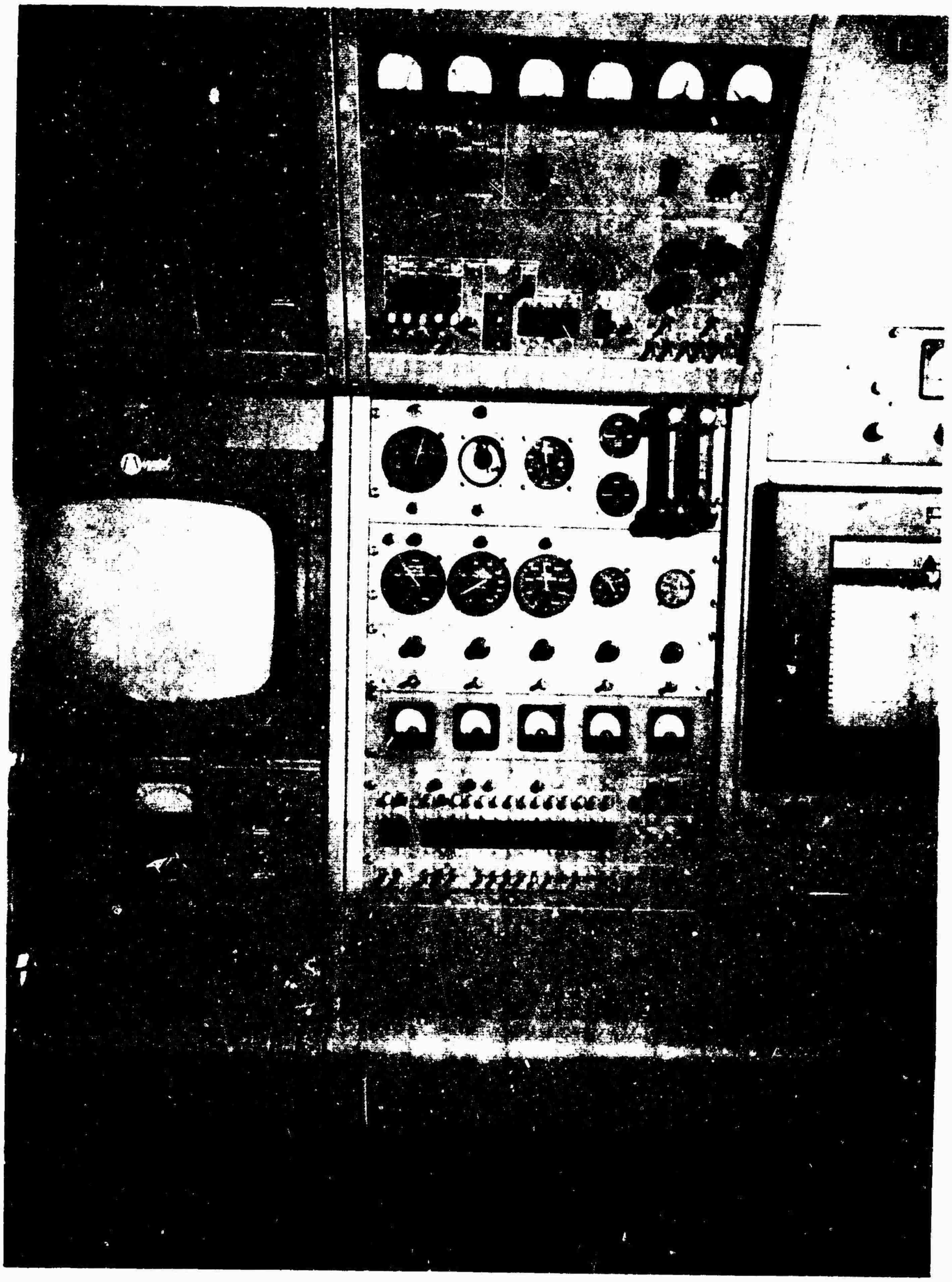

Figure 3. Outside Monitor Console of Two-Man Simulator

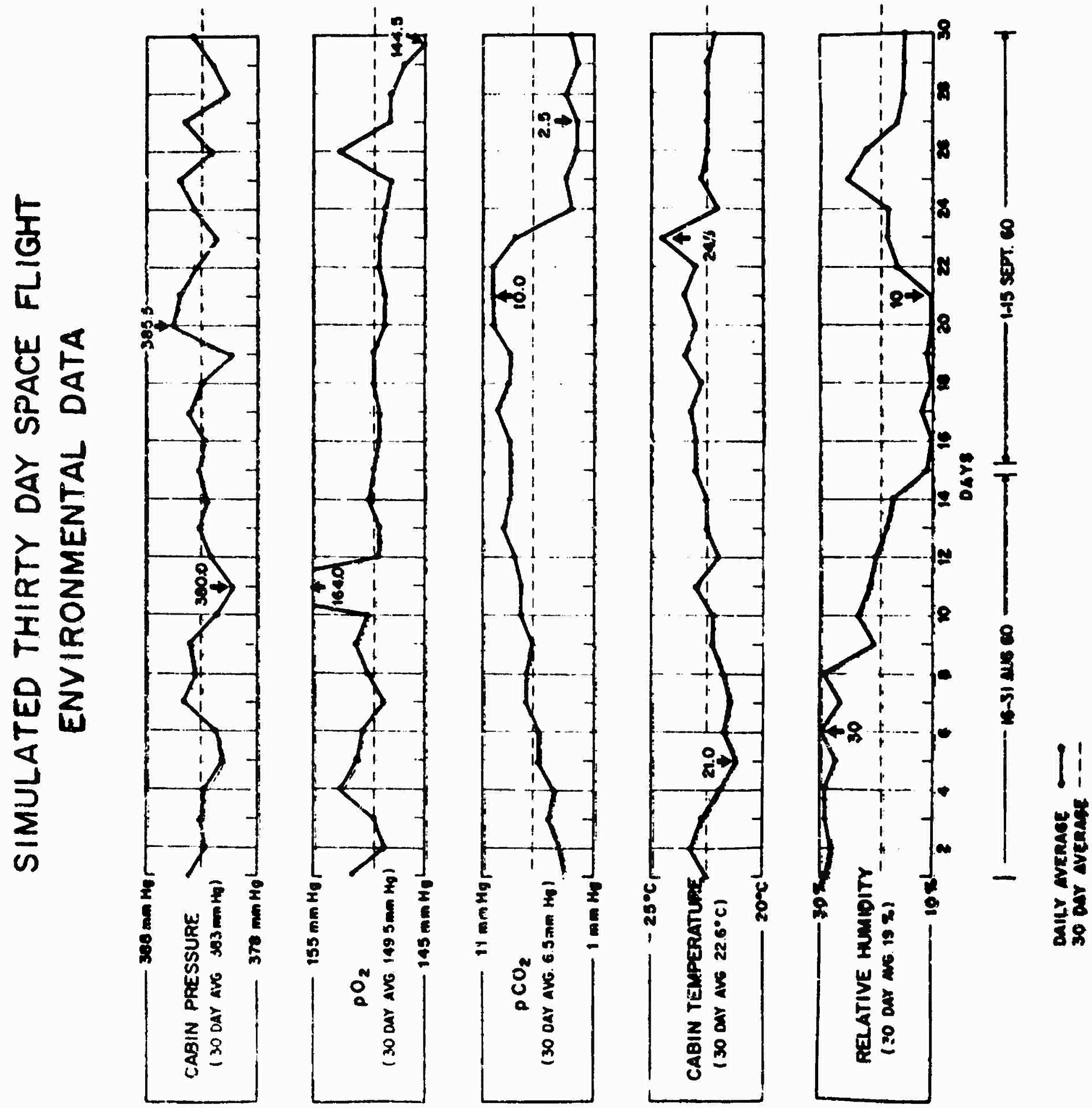


**Figure 4. Environmental Parameters During Thirty-Day Flight**

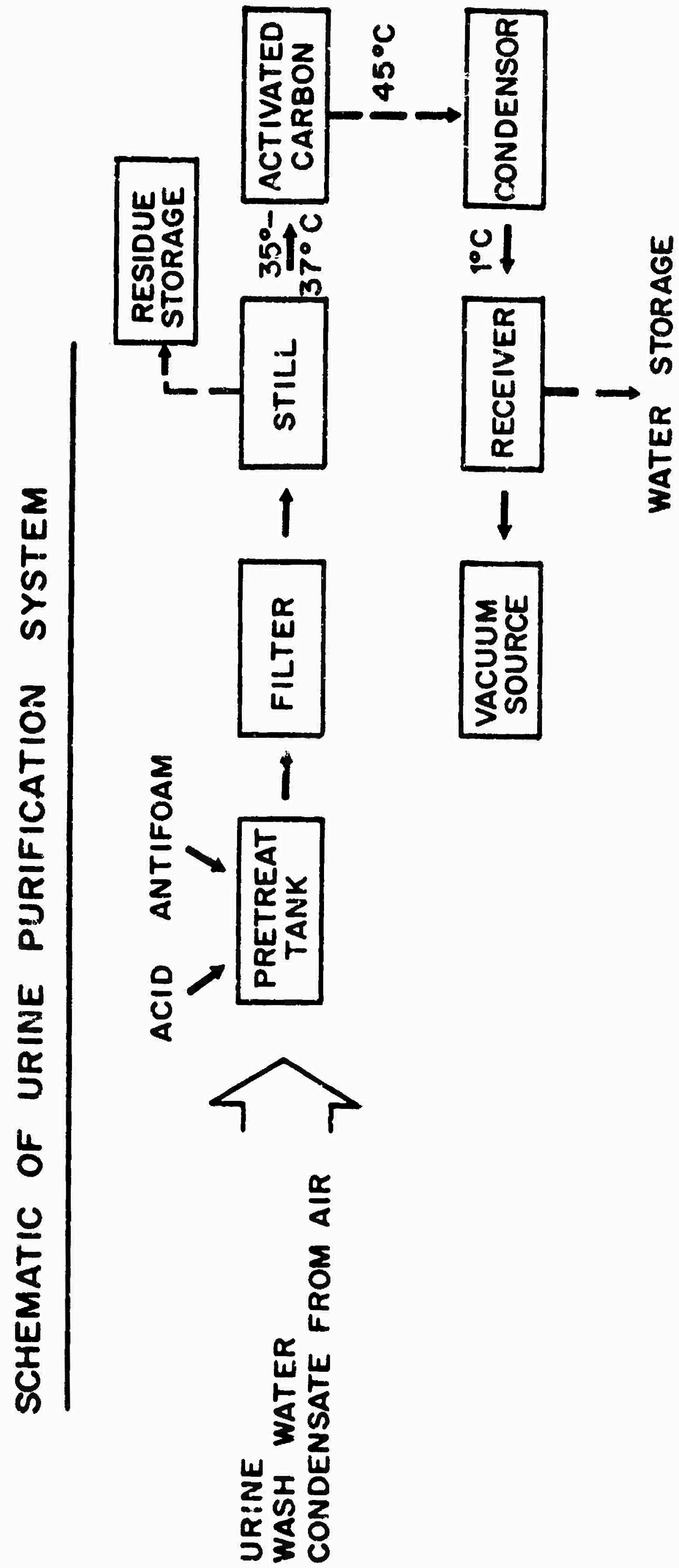


Figure 5. Schematic of Water Purification Apparatus

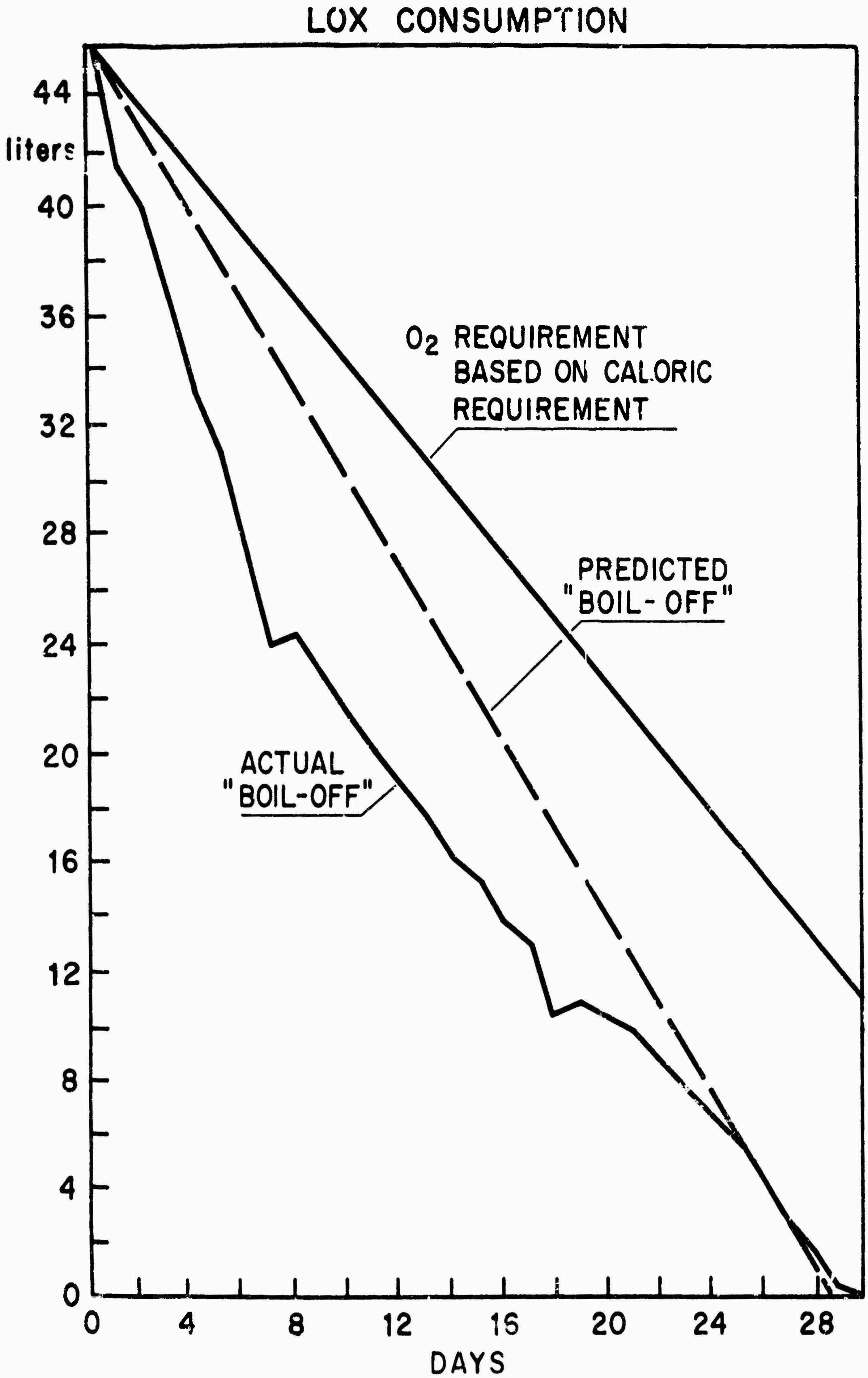


Figure 6. Oxygen Requirement Data During Thirty-Day Flight

# SIMULATED THIRTY DAY SPACE FLIGHT PHYSIOLOGICAL DATA

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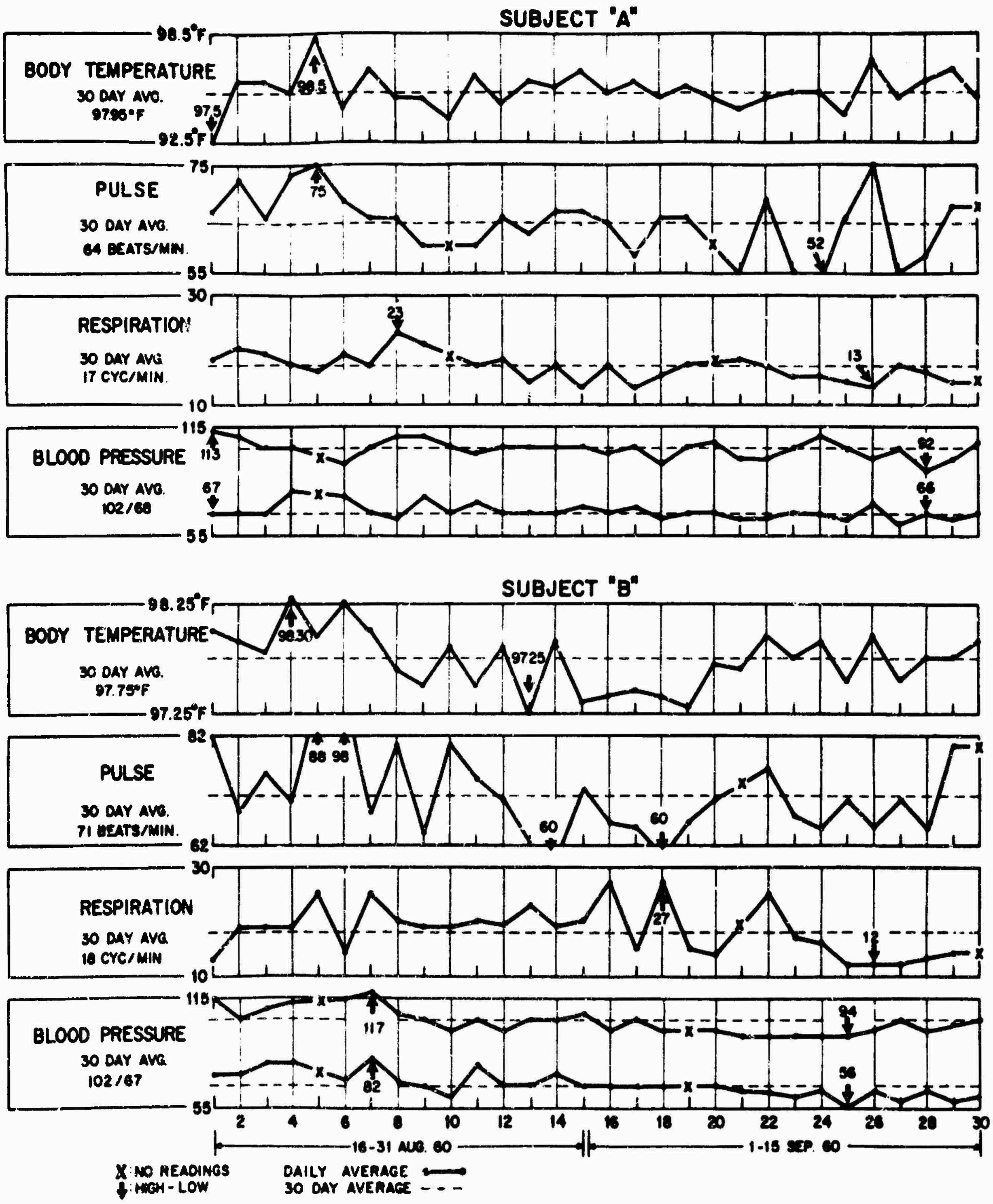


Figure 7. In-Flight Physiological Parameters

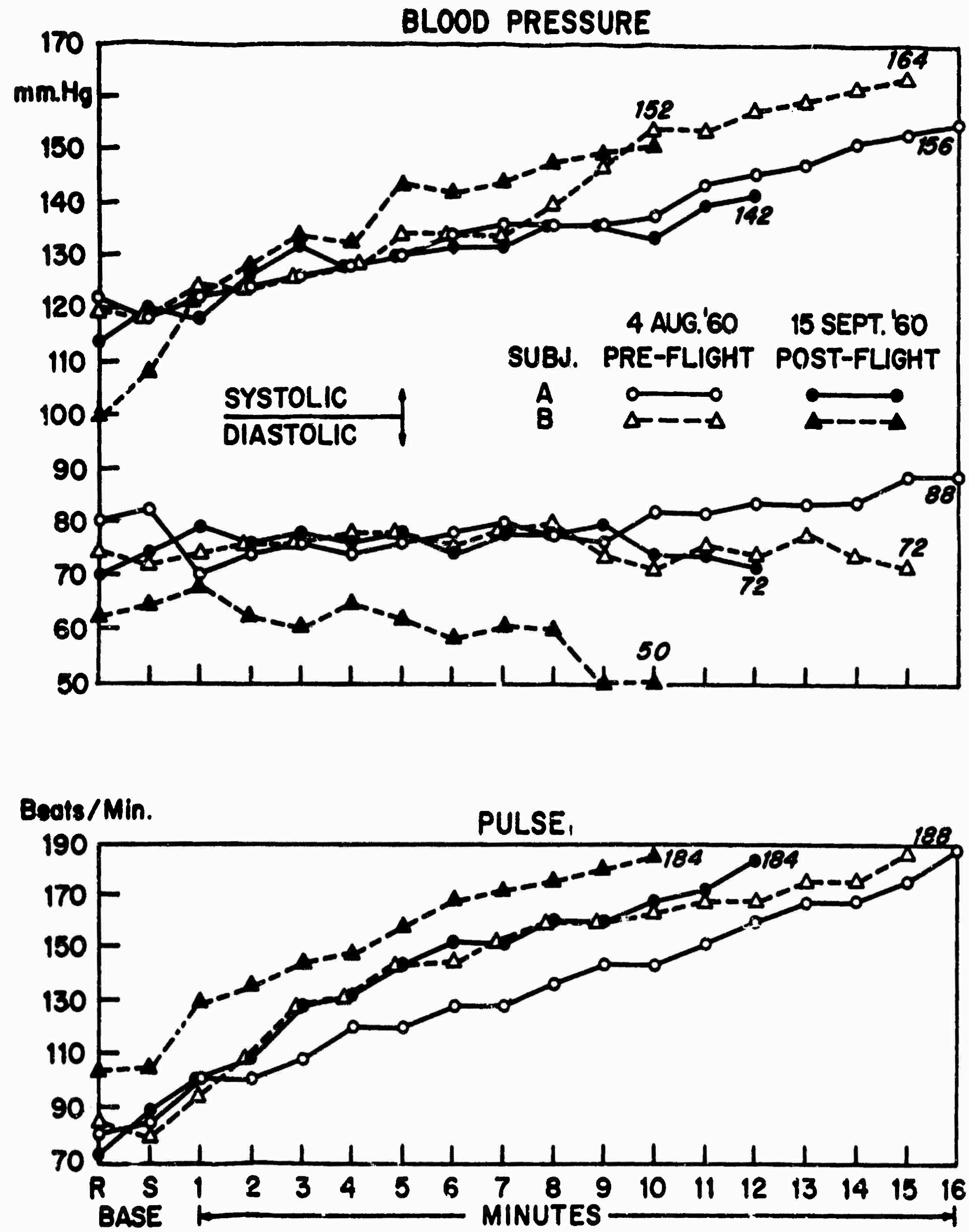


Figure 8. Work Capacity Data Pre and Post Flight

LECTURES IN AEROSPACE MEDICINE

# EXPERIMENTAL APPROACH TO THE PSYCHO-PHYSIOLOGICAL PROBLEM OF MANNED SPACE FLIGHT

Presented By

Bryce O. Hartman, Ph.D

Chief, Psychology Section

Neuropsychiatry Branch

School of Aviation Medicine

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# EXPERIMENTAL APPROACHES TO THE PSYCHOPHYSIOLOGICAL PROBLEMS OF MANNED SPACE FLIGHT

By

Bryce O. Hartman

In less than a decade, manned space flight has become a significant problem area for aviation medicine. The magnitude and multiplicity of the obstacles to putting man into space have led to the establishment of major research programs in space medicine. Staffing at the School of Aviation Medicine is in accordance with the team concept, and centers around a core of specialists in Aviation Medicine and aviation physiology, supported by physical, biological and behavioral scientists. Each problem is approached from the multi-discipline point of view. The extent of the participation of the various elements of the team is dependent on the nature of the problem and the applicability of existing scientific knowledge. As a result, each discipline participates in several different programs in varying degree.

To the outside observer, the resulting interwoven activity might appear like a tangled hank of yarn. This is not the case. Unifying concepts have evolved which provide an operating philosophy and some guide lines for organizing elements into effective working groups. Figure 1 illustrates the approach. In figure 1, I have modified a composite graph which originally summarized the effects of relative humidity and temperature (wet and dry bulb) on human behavior. We shall not be concerned with the specifics of this problem. Rather we shall use the figure to demonstrate that various combinations of physical and environmental stressors yield an area within which man as a biological specimen survives and functions.

NOTE: This manuscript reflects the views of the author and should not be considered official Air Force policy.

I want to use figure 1 not only to illustrate the organizing concepts, but also to demonstrate the role of psychophysiology in the problems of space medicine. A definition of psychophysiology is in order at this point. Psychophysiology is, in a general sense, a wedding of the physiologist at one end and the experimental psychologist at the other. It focuses on molar behavior at all levels, with less attention on further breakdowns to specific systems or the analysis of specific mechanisms. It's areas range from studies of skill, proficiency, and reliability (or resistance to decrement in performance) at one end, to the analysis of gross aspects of sleep and gross arousal levels measured bioelectrically at the other. As the activities in our psychophysiological program are described, this definition will become more specific. Let us turn now to an analysis of the concept illustrated in the graph.

In this discussion, survival is the first key word. The limits--the boundaries of the area in figure 1--can be considered to be finite and unequivocal. The man survives, or he dies. The second key word is functions. This is neither finite nor unequivocal. The functions we are talking about range all the way from the man close to the survival limits in our graph who is still alive but is non-functional, to the man in the center who is not only alive, but is also comfortable, effective, and capable of performing the most complex kinds of tasks.

First, let us see where we stand now. In terms of the current state of the art, in space medicine as well as space technology, the problems of

putting man into space are primarily physiological. The major practical problem of space medicine today is to produce a habitable micro-environment, and to extend the habitability of this micro-environment for increasing periods of time. Until this habitable environment is achieved, the behavioral scientist must work on very general problems, and can contribute little to the solution of specific problems in any specific weapons system. For relatively short periods, we have already achieved a useable micro-environment. Longer periods involve extended on-board logistical support, more complex vehicle construction, and increasing significance of environmental and physical stressors previously of little importance, all interacting in a complex fashion.

Once survival is achieved, space medicine moves into a graded series of problem areas. These are shown in general form in figure 1. The outer boundaries constitute the survival envelope. Minimum survivability, the zone adjacent to the survival envelope, involves major physiological problems. These focus primarily upon survival without damage to the occupant. In fact, the problems here might be considered more biological than physiological.

A little farther in are problems concerned largely with survival without cost to the occupant, irreversible damage now having been eliminated from consideration. In this zone, we become concerned not only with cost, but also with the ability of the occupant to function in some gross sense. For the first time, psychophysiology has a specific contribution to make. In

this zone, the psychophysiologist can support the physiologist in his assessment of the effectiveness with which gross functions are carried out. The role of psychophysiology is, however, supporting and secondary.

As we move inward toward the core of the survival envelope, we enter the zone where psychophysiology plays a major role. Problems in this area require the participation of the physiologist and psychophysiologist in the true sense of joint participation, each contributing equally to the assessment of problems. In this zone, the man now begins to perform functions which make a measurable though low order contribution to overall system performance. Problems in this area still require the assessment of cost to the occupant, but now the cost arises from the functions assigned to the man rather than from the effort of combating the environmental and physical stressors.

Finally, we move into the core. Here, man makes significant contributions to system performance. Successful completion of the mission is not possible without effective performance on his part. His higher-order capabilities are exploited as fully as possible. Problems of his proficiency (skill) and reliability become paramount. Psychophysiology becomes primary and the other disciplines take a supporting role.

This schema for an integrated team approach is straight-forward for space medicine. It provides an orderly progression to the steps for solving problems of putting man into space. But when we turn our attention to specific manned space weapons systems, we run into a complication. The designers

and engineers for these weapons systems are concerned with very functional kinds of questions. They are not content with survival without damage, or without cost. They want answers couched in terms of proficiency and reliability. Their requirements force us to plunge directly toward the core of the survival envelope, despite lamentable gaps in the literature and a distressing paucity of information on what man is going to do in the significant systems role he is being given. Our problem is to make this plunge with as few errors as possible.

This, then, gives a general picture of the framework within which the psychophysiological problems of manned space flight are approached. In the remainder of this paper, I will describe the work which we have been doing. Three major areas will be discussed: Our participation in the weightlessness problem, in the Space Cabin Simulator program, and in the analysis of dynamic behavior in the space cabin environment. In limiting my presentation to the psychophysiological program being carried out at the School of Aviation Medicine, I do not mean to imply that there are not other programs of significance. Other agencies, such as WADD, the Naval School of Aviation Medicine, and the centrifuge facility at Johnsville, are making valuable contributions to the problems of putting man into space.

### Psycho-biological Aspects of Weightlessness

Weightlessness is one of the major psycho-biological problems of manned space flight. Survival, as such, is probably not a significant aspect of

prolonged weightlessness. In terms of our conceptual schema, however, the ability of man to function, even in a crude way, is most certainly questionable. The effects of prolonged exposure to the zero-G environment have proved to be exceptionally difficult to study. No techniques for producing prolonged periods of true weightlessness have been developed. Centrifuges have been of very limited value. The use of elevators and parachute drops has also been suggested, but such technique produced the weightless state for only a few seconds at a time. Flying an aircraft through a Keplerian trajectory has become a standard technique for producing longer periods of weightlessness. Weightless states on the order of a minute can be obtained by this technique, but it is apparent that this is far short of an effective procedure for analyzing prolonged periods of weightlessness.

The School of Aviation Medicine has made many valuable contributions to the evaluation of the problems created by weightlessness. Theoretical analyses have been made by Strughold (17, 18), Ritter and Gerathewohl (16), Haber and Haber (9), Haber (10), Gerathewohl, Ritter and Stallings (2), Haber and Gerathewohl (11), and Lamb (14). Using the Keplerian trajectory, a variety of physiological, functional and psychological changes have been studied experimentally. Ward, Hawkins, Stallings have studied problems of micturation (19) and nourishment (20). Hawkins (13) has used the Keplerian trajectory as a means of familiarizing the Mercury Astronauts with the experience of weightlessness. Gerathewohl (3, 4, 5, 6, 7) has studied several psychological aspects. The studies involving short periods of weightlessness can be

summarized as follows: (a) Many biological functions, such as eating and micturation, present problems, but these problems can be solved; many psychological functions, such as visual perception and motor coordination, will suffer some minor impairment, but the decrement is far from significant and the astronaut can compensate for the losses. This optimistic point of view must be tempered by the potential effects of prolonged exposure, which the theoretical analyses cited earlier have isolated as major obstacles. For example, we might assume that weightlessness will pose no special performance problems for the astronauts. At the present time, this is only an assumption. But these earlier papers do provide us with a jumping off point for other studies.

We must continue to be concerned over the effects associated with long periods in the weightless state. Gerathewohl (8) in an excellent review of the physics of weightlessness and the history of research on the problem, emphasized that prolonged weightless will produce major changes in the astronaut. He suggested that man <u>will</u> be able to tolerate prolonged exposure, but that this is not the problem. The real difficulty will be his ability to readjust to the one-G state upon return. He felt that the physiological effects (as in circulation, digestion, and muscular function) of returning to the normal gravity environment will involve major disturbances. He pointed out that the astronaut's job will be largely an "automatic, push-button affair" and that only on re-entry will skill be required. It is precisely at this point, however, that major physiological disturbances (and

concomitant performance disruptions) will occur.

Getting at the problems of prolonged exposure is exceptionally difficult. Earth-bound researchers have been limited by their inability to produce prolonged periods of weightlessness. Brief periods of zero-gravity produced by aircraft flying a Keplerian trajectory give us only a peek at many of the problems. Water immersion is one technique for partially simulating prolonged weightlessness. It creates many of the effects of weightlessness, particularly with respect to the musculo-skeletal and cardiovascular systems. In particular, in the hypodynamic environment, as in the zero-G environment, considerably less work is performed in carrying out a variety of functions.

Early this year we carried out an exploratory study in collaboration with the Space Medicine Department on the effects of prolonged weightlessness, using the water immersion or hypodynamic technique. Because the problem is basically biological, the primary experimental procedures were physiological and medical. Work capacity, for example, was measured by the treadmill test developed by Dr. Bruno Balke during the many years he was here at the School. But losses in work capacity cannot be directly translated into decrements in the ability of a man to perform assigned operations in a functional space vehicle. Therefore, psychological tasks requiring psychomotor performance like that which might be required of an astronaut were added to the behaviors being studied. In addition, since sleep requirements in prolonged weightlessness are of concern, sleep behavior as measured by

EEG was added to the study. We ended up, then, with a team from medicine, physiology, and psychophysiology, exactly as one would predict from the concept presented in my introduction.

The study required six weeks to complete. The schedule is shown in figure 2. The subject spent the first ten days adjusting to a special diet selected to minimize the disposal of feces and to provide a known nutritional intake. From day 11 through 27 a series of metabolic and functional tests were carried out to establish baselines. This period included a 50-hour trial run of immersion. After recovery from the trial immersion, a period of seven days was spent in the tank. Pre-immersion, post-immersion, and recovery measures were obtained for all procedures.

The device used to produce the hypodynamic environment was a water-filled tank, shown in figure 3. A stable platform for the subject was provided by a contoured couch. Water temperature was maintained at 33°C by a heater. Psychomotor tasks were placed in a console installed on top of the tank. A regular schedule of eating, sleeping, performing the psychomotor tasks, and taking physiological measurements was followed. Included in this schedule was one hour each day out of the tank for a clinical evaluation and skin hygiene.

The results have been reported in three SAM papers. Graveline and Balke (1) obtained pronounced functional deterioration. Cardiovascular reflexes were severely disturbed and muscle tone diminished. There were marked deviations in blood and urine biochemistry. In the psychomotor area,

we (12) obtained systematic though minor changes in performance during immersion and gross disruptions in psychomotor behavior upon return to the normal one-G environment. The results on sleep behavior (15) were extremely interesting. First, there was a marked reduction in the amount of sleep needed. The subject, who normally sleeps a full eight-hour night, required less than four hours. Second, there was a marked constriction in depth of sleep, the most characteristic state being approximately light sleep, from which he could be easily aroused. Despite these marked alterations in sleep behavior, the subject gave every indication of being relaxed and refreshed each morning.

In terms of the practical problems of manned space flight, the study provided several different kinds of information. First, both in terms of psychomotor proficiency and physiological functions, the subject tolerated this quasi-weightless state very well. This finding agrees with results obtained from brief periods of weightlessness. Second, gradual and progressive alterations in physiological functions occurred during prolonged exposure. These culminated in marked intolerance for the normal one-G environment, a condition best characterized as marked debilitation. As a result of this debilitation, there were marked losses in functional capabilities. There was, in other words, marked biological impairment. The gross disruption in psychomotor performance which was obtained after prolonged immersion suggests that the biological impairment may be sufficient to prevent the man from performing meaningful tasks in a space vehicle during re-entry. The

problems of re-entry just described was our third finding. The fourth result, on sleep behavior, strikes a more optimistic note. It appears that sleep will not be the problem which might be anticipated. There may even be some bonuses. Less sleep may be required, which would leave the astronaut free for a longer work day. Furthermore, if the sleep findings can be extended, astronauts may have a reduced susceptibility to fatigue.

These, then, were the findings in our exploratory study. We identified some significant elements of the weightlessness problem and reached some tentative conclusions. The conclusions are testable. They should be examined in a series of studies to follow up the leads in this first look at prolonged weightlessness.

## Proficiency Aspects of the Space Cabin Simulator Program

The SAM Space Cabin Simulators are the focus of a broad program involving several different elements. Most of these are described by Dr. Billy E. Welch, who is in charge of the program and the simulators. I will not go into these elements, except to point out that one major problem area is that of closed ecological life-support systems and another is that of logistical support requirement for manned space vehicles. The importance of these efforts is obvious. A third element is that of the maintenance of psychomotor proficiency in this simulated space environment for prolonged periods of time. This problem h  two aspects. First, factors influencing astronaut proficiency are of interest in and of themselves. Second, changes in proficiency can be valuable adjuncts to evaluating physiological and systems data

obtained directly from the subjects and the simulator. Our contribution to this broad program has been to provide the psychomotor elements.

My group has worked, to this point, only with the two-man simulator. The program with the two-man cabin is an extension of the earlier research with the one-man cabin. In that program, Hauty made explicit the concept of operator reliability, using it as a more operational statement of the problem of the maintenance of proficiency at a level acceptable for over-all systems function. It is obvious that operator reliability has special significance for space flight, because of the extended commitment of the astronaut to the task and that fact that support or relief is feasible only to a minimal degree. Hauty's three years of research focused primarily on fatigue and diurnal variation, backed up by his earlier work on fatigue problems in military aviation. Before describing our own work, let me summarize results from the earlier program.

## Fatigue Effects

Hauty (25) emphasized that the fatigue problem in space flight is complicated by the prolonged commitment of the astronaut to a set of complex functions and by the deleterious effects of loss of sleep. He pointed out that performance deteriorates rapidly in simple tasks requiring detection of single signals. Such simple tasks will obviously be a part of the astronaut's job. He also emphasized the importance of individual differences in susceptibility to fatigue. Additional problems are the cumulative effects,

deleterious subjective changes, and inadequate perception by the operator of the decrement in skills which have occurred.

In a subsequent paper, Hauty (27) further emphasized the differential fatigue effects in different classes of tasks. The operator system in the one-man Space Cabin Simulator, shown in figure 4, required several different kinds of performance. Hauty concluded from his results that tasks based on gross, discrete cues are more resistant to fatigue than tasks based on <u>minute</u> cues, in which vigilance and alertness are important. He stated that vigilance is the function most affected by fatigue, a finding well supported by other research.

In a report on seven-day flights in the SAM Space Cabin (29), Hauty presented data showing that four pilots maintained proficiency within days and across days when following a working schedule of four hours on and four off. In contrast, his data on a series of 30 hour runs requiring continuous work (26) on the same tasks showed progressive decrement. He concluded that human reliability cannot be extended much beyond 20 hours of <u>continuous</u> work and that space flights should be programmed to maintain the most effective phase relationships between man's physiological cycle, the period of operation, and local time. He again emphasized that operator reliability could be improved by reducing the vigilance load.

In another paper based on prolonged runs in the SAM Space Cabin programs, Gerathewohl (21) used Kraeplin's work performance test (addition of digits). Gerathewohl stated that this test is particularly sensitive to

changes in proficiency at a long monotonous task. In contrast to Hauty's results, Gerathewohl found that the volume of work done increased each day, and that errors and corrections also increased. It is apparent that, even in the systems environment, the kind of fatigue effect obtained is dependent on task characteristics.

Diurnal Effects

Diurnal variation is the other main factor studied in the one-man cabin program. Shifts in proficiency as a function of this cycle are hardly acceptable for space flight. One way around the problem would be to develop techniques for adapting a man to a different cycle matched to the requirements of any specific space mission. But can man be adapted to other schedules? The seven-day runs in the SAM Space Cabin, previously described (29), examined this problem. Instead of the normal schedule of 16 hours of activity and eight hours for sleep, subjects worked on a four-on, four-off schedule. Subjects quickly adapted to this schedule, sleeping part of every rest period both day and night. One subject showed only partial adaptation, sleeping little during the middle rest period, but this subject also had less total sleep than the others. The stability of performance across the three work periods each day was further evidence of effective adaptation. It appeared at this point that the diurnal cycle is easily altered. However, two subsequent runs of 30 hours duration with the subject performing continuously threw a different light on the problem. One run started at 1400 hours. This

run showed an abrupt loss of proficiency during the period normally devoted to sleep. In the other run, started at 0600, no such abrupt loss appeared during the period normally devoted to sleep. Both subjects showed the decrement in performance after 20 hours which has been previously described. Hauty (26) concluded that careful attention must be given to diurnal variation. Specifically, it appears that short space flights involving continuous work by the astronaut should be initiated at a point in the day where diurnal effects will be minimized.

In the one-man cabin studies, then, both factors were shown to be significant variables under certain special circumstances. Fatigue appears to be the more important of the two. Continuous performance is the key condition under which fatigue is an important problem. The diurnal cycle seems to be less of a problem. Again, the short flights requiring continuous performance require special consideration. It appears that diurnal effects on operator reliability can be minimized with relatively simple procedures, at least in terms of proficiency effects, and sleep schedules. These conclusions are subject to modification. Prolonged weightlessness may alter the long-term effects considerably.

## Two-Man Cabin Program

The two-man cabin involves more than just a continuation of the one-man cabin program. First, and most obvious, it provides for two subjects, or even three under certain conditions. Second, it involves major advances in the closed ecological life-support area, including waste disposal and water recycling. Furthermore, the ecological aspects are more nearly "on-board."

Third, there are major advances in the logistical area, again including more "on-board" support features. And fourth, there is significant improvement in the operator task, or psychomotor apparatus. The apparatus contains many more elements, each of which is more "operationalized" to improve subject acceptance and face validity. It also has the capability of imposing a greater work load on the operator, which improves its sensitivity to the many functions being studied. The apparatus was developed by Hauty, who utilized some of the tasks and concepts which we have developed in our research on man as a systems operator as well as his own analysis of the astronaut's job. This last point is important. The astronaut is not going to be a space vehicle "pilot." He is going to function as the operator of a complex, semi-automatic system in a manner much like operators of many other advanced weapons systems.

The simulator imposes three broad categories of requirements on the subjects--management of the logistical aspects of simulated space flight (disposal of wastes, recycling of fluids, preparation of foods, etc.) management of the internal environment (control of atmospheric contaminants, etc., achieved through an environmental control panel in parallel with a similar system external to the cabin), and management of the operator system. While both the logistical and environmental functions involve a broad kind of proficiency, no attempt has been made to this point to evaluate operator effectiveness in these areas. Rather, an over-all evaluation of the simulator and its various sub-systems will be obtained for these functions. In contrast,

the operator system has no direct effect upon over-all system efficiency. It is, in effect, a completely independent sub-system, and has as its sole purpose the evaluation of the functional effectiveness of the men in the system during the flight. The remainder of this section will be concerned exclusively with the operator system.

Description of the Operator System

The operator system consists of six units: the master programmer, which programs and selects signals in the several tasks which the operator must perform, an assembly of sub-programmers which operate these tasks, two parallel display units, one inside the cabin at the operator's station and one outside for monitoring the system, an assembly of controls inside the cabin for performing the tasks, and a recording unit which gives a time history of performance and a measurement of response time for each signal displayed to the operator.

So far as the subjects are concerned, only the displays and controls inside the cabin are relevant. These are mounted in panels (shown in figure 5) on the left half of the operator's station, the right half being occupied by meters and controls for the environmental control system. The displays are scattered across three panels and are predominantly visual, only one task using an auditory signal (Morse Code). There are a variety of visual displays, including different types of meters and lights, in addition to one task presenting pairs of block-design patterns by closed-circuit TV. The controls are located on the two sides of the lower panel, and are either

lever-type or push-button switches. Compatibility of each set of controls and displays is achieved by location on the panel, the physical management of homogenous groups of controls, color-coding, and variations in operation and appearance for each task. A total of 14 tasks are in the system. The net effect of assembling a variety of tasks in one unit for one operator to perform is to produce a simulated systems task which is, in our nomenclature, multivariate.

In operation, most signals appear at the operator's station at regular intervals (72 seconds) but in varying combinations. Two tasks follow a different schedule in that the auditory task presents a new signal every five minutes and the matching task presented on a TV screen is on continuously and requires constant monitoring. All but the matching task have but one mode of operation--the programmer turns the tasks "on," and they stay on till the operator turns them "off." Time "on" for each signal is the measure of proficiency.

Signal rate (number of signals per unit of time) is a basic variable in systems tasks such as these. The operator system has three basic speeds built into the programmer. Twelve of the 14 tasks can be set at any of the three speeds; each independently of the other. Because of this feature, signal rate can be varied from 175 events (signals) to 350 per hour. By turning some tasks off, even lower signal rates can be obtained. The addition of signal rate permitted us to study a new variable in the program--work load. Work load is a factor effecting operator reliability, but in an instantaneous way

rather than in terms of long-term, cumulative effects like those seen in fatigue. The significance of short-term factors in operator reliability was discussed in my paper at the recent symposium on "The Psychophysiological Aspects of Space Flight" (22).

In order to give the subjects motivation and a frame of reference for operating the system, the tasks were given descriptive names and functions simulating those which man in space might be expected to perform. The tasks were conceptually assembled into four functional areas. The first was the Navigation and Orbital Flight Computer system which simulated the tasks of feeding position information via a polar-equatorial grid system into an airborne computer and monitoring a flight control servo system for controlling vehicle orientation. This system consisted of the "Polar and Equatorial Matrices," the "Gyro-Servo Sensors" and corresponding controls. The second area was the Airborne Radar and Doppler Position System (ARAD) which simulated operator tasks involving the continuous monitoring of a radar-type scope and position identification via auditory signals. This display involved the "ARAD Scope" and controls and a "UHF Code Panel." The third area of function was that of problem solving and decision making. Here the operator monitored a simulated Nuclear Power Control System via a display called "Reactor Control Monitors." This required him to override a machine system by solving simple problems in Boolian algebra using the "Reactor Servo" controls. The fourth area was that of monitoring displays and manipulating controls simulating a Data Telemetry System for gathering, encoding

and transmitting scientific data to ground-based stations upon command. This required simple data processing and differential control functions on the part of the operator. These displays consisted of a "Solar Radiation Monitor" and corresponding "Telemetry Coding" panel and "Radar and Infra-Red Lock-On" with related controls. An operating manual which elaborated on these names and functions, and which instructed the subjects on how the tasks were to be performed, was written. It appeared to have high acceptability for the subjects, and contributed to their motivation.

The Simulated Mission

Another technique to add realism to the flight and to contribute to the motivation of the subjects was the development of a mission. For the first 30-day flight completed this summer, the following mission was developed. Some constraints in the selection of a "plot" are imposed by certain tasks in the operator system and by other repetitive requirements placed on the subjects, such as reporting periodically to "ground-control." Because of these constraints, we selected an orbital mission, rather than a "lunar probe" for instance. Each orbit was completed in 90 minutes. The repetition of signals and the periodic reports made sense in this frame-work. There were 16 orbits each day, and a total of 475 orbits in 30 days. A schedule was provided for keeping track of their progress day by day in terms of orbits. We hoped that this sort of "progress" would also contribute to

motivation.

The 30-Day Schedule

The crew structure for this first 30-day run was that of two crewmen serving alternately as the system controller. The schedule which was developed consisted of 15 consecutive two day "packages." This schedule is shown schematically in figure 6. In each two day unit, each operator manned the system ten hours on one day and 12 hours on the alternate day. Each day the system was manned a total of 22 hours, with two one-hour periods (0700-0800 and 2000-2100) of ground control to complete the 24 hour cycle. Each subject manned the operator system for a three-hour work period, (mornings) a two-hour work period, (afternoons) and a five-hour work period (nights) each day. In addition, each subject had another two-hour work period every other day to provide for the rotation of subjects each day. In a two-day unit, each subject was on duty during every one of the 22 hours the system was manned. The long work-periods at night permitted the subjects to sleep as much as six or seven hours at a single stretch each day.

The ground-control hours were not completely free. The auditory task (Telemetry Coding) and matching task (ARAD) remained on, with the correct responses being made by either of the subjects. These hours were considerably less structured in order to provide periods each day when interpersonal behavior could be evaluated in a relatively unstructured setting. Interpersonal behavior was studied as a separate element of the over-all program.

During each ground-control period, the operator system was set to a new speed. Two speeds a day were scheduled. With this schedule, each six days was a "package," and yielded two sets of data for each of three speeds on each operator at each duty period. In 30 days, there were five such "packages."

It might appear, since only one subject manned the operator system at a time, that there was a considerable amount of free time. This was not the case. In addition to the required sleep periods, there were a variety of other duties to be performed, including fixing meals, operating the waste disposal and water-recycling units, checking and calibrating the environmental controls, etc.

The Variables Under Study

The psychomotor aspects of this first 30-day flight were under the supervision of Dr. R. E. McKenzie. A variety of variables effecting proficiency at this simulated systems task were under study:

(1) The effect of prolonged commitment (30 days) of a two-man crew to a systems task under some simulated space flight conditions.

(2) Duration of the work period. There were two-hour, three-hour, and five-hour periods for this evaluation.

(3) The effects of differing signal rates, with five six-day units for this.

(4) Circadian variation. The first two hours of each work period were

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used for this evaluation. There was some contamination of this variable by our fixed schedule (i.e., the five-hour work periods always occur at night). Nevertheless, it was possible to at least explore the effects, as a guide to future flights.

(5) The several interactions of these variables.

The performance data from the first 30-day flight are still being analyzed. It appears likely, however, that there are no major differences to any of the variables just listed for either subject, though this should be regarded as a tentative summary only. There are interesting differences in performance for night versus day in the case of both subjects. One was more effective during the afternoon and the other was more effective at night. Because of this difference in the two subjects, however, it is probably not correct to attribute the difference to diurnal variation. A report on this flight will be published this spring (28).

Our general results (no major differences) are like those obtained by Hauty in the seven-day, one-man cabin flights. There are at least two possibilities in these results. The results may be valid because the subjects did not perform continuously in either this run or the earlier seven-day runs. As an alternative, the results are not valid because the operator systems in both simulators were too "tolerant" of operator decrement, i.e., they were too insensitive to changes in proficiency. Furthermore, in our flight the psychomotor work schedule had to be adjusted for time lost in repairing cabin malfunctions, which kept one and sometimes both subjects otherwise

occupied. The two-man cabin operator system is being modified now to permit operator loads which our own systems research (23, 24) have demonstrated to be in excess of the operator's capabilities. This modification will permit us to evaluate the latter possibility. At the moment, however, we have a tentative confirmation of the results of the one-man cabin flights where the operator had a regular schedule of work and rest.

## Aspects of Dynamic Behavior in the Space Cabin Program

There is another aspect of our participation in the space cabin program which requires separate consideration. This is the study of what might be described as a clinically oriented evaluation of dynamic behavior, as contrasted with the experimentally oriented analysis of operator proficiency discussed in the previous section. For this element of the program, a behavioral science team consisting of clinical psychiatrists and clinical psychologists was assembled. This team had two objectives during the one-man cabin flights: (1) to identify gross changes in dynamic behavior resulting from the flight, using pre- and post-flight psychiatric evaluations and psychological tests; and (b) to evaluate any aberrant behavior which might occur during the flight. The behaviors in this latter objective, which have received the most attention, were the kinds of effects obtained in isolation, confinement, and sensory deprivation studies.

The background for our work in this area is given in a review of sensory deprivation studies by Wheaton (34) in 1958. Wheaton's review ranges from

anecdotal material to laboratory studies, and provides a useful, concise summary of the problem. Let me briefly summarize my point of view on this problem, which I prefer to call "the emotional aspects of unusual environments."

Historically, the current interest in isolation and confinement problems arose during the Korean War. A national concern developed over the behavior of American prisoners-of-war, though much of the information being disseminated at that time has been since demonstrated to be faulty. Again on the basis of basically faulty information, we assumed that one of the techniques used by the captors was a combination of isolation, confinement, and sensory deprivation. A series of laboratory investigations of this unusual environment were initiated, and some most interesting results were obtained. Illusions of all kinds, and losses in a variety of intellectual functions and modes of behavior were reported. In time, it became apparent that the POW problem was not concerned with this unusual environment. However, a most stimulating area of basic research on behavior was under way. It has continued to be a fruitful area for the behavioral scientist.

When the results of these studies are combined with additional information gained from the effects of other unusual environments, such as those which produce the break-off phenomenon (Graybiel), the cataract psychosis (Greenwood), and the respirator psychosis (Mendelson and Foley), a clear picture emerges. This picture can be summarized in four steps. First, in unusual environments, there are emotional responses which occur in perfectly

normal people. Second, these emotional responses can range from minor perceptual aberrations and minor changes in over-all emotional states to extremely dramatic, almost hallucinatory kinds of reactions. Again, we are still talking about perfectly normal people. Third, there need not be any specific physical or environmental stresses involved in these situations. Under stressors, we need to include both external stresses such as alterations in the oxygen content of the air or high heat loads or G forces, and stresses within the organism such as fatigue or some disease process. When these are present, the effects are sometimes more dramatic or more acute, or may appear sooner. Nevertheless, they are not necessary for the occurrence of emotional responses. And fourth, these effects are usually transient, recovery is rapid, and the effects have little bearing on the psychiatric or mental health state of the individual.

What does all this have to do with space flight? It is apparent that, in a space vehicle, we have an environment similar in many ways to the isolation and sensory deprivation situation. Wheaton, in another paper (35), details these similarities, and goes on to emphasize the critical nature of a vehicle malfunction. In that paper, and the one cited earlier (34, 35), he also emphasizes the role of individual personality characteristics in susceptibility to these effects. He points out that the SAM cabin program is an ideal place in which to study these problems. It is these kinds of problems which are being evaluated. One of the problems in this research is that you have to wait for "something" to happen. Fortunately, a variety

of events have occurred.

First, I want to discuss the results of the one-man cabin flights. Only minimal emotional disturbances occurred in the seven-day flights, with one exception. With all subjects, but in varying degrees, there was a gradual build-up in hostility, directed toward the crews outside the cabin. With one subject, the hostility increased to a point where there was a possibility that the flight would have to be terminated. This hostility occurred despite the high motivation of the subjects.

In the 30-hour flights, the results are much more interesting. An intensive evaluation of four such flights have been conducted. Steinkamp and Hauty (33) report that all four subjects experienced aberrations of some kind and in varying degree. They point out that in each case, the experience reduced operator proficiency. This suggests that these events can be a factor in over-all systems reliability. Flaherty, et.al. (30) present a more detailed analysis of the experiences of these four subjects, adding background information and a summary of the pertinent elements of the psychiatric and psychologic evaluation. They point out that illusions which involve plausible elements are a special problem of operator reliability, because the astronaut may regard them as "real" and initiate a course of action disastrous to the vehicle. They emphasize the need for psychological nurturance in the space flight environment. This might be considered to be a requirement for supportive therapy as well as for an environment constructed to keep the astronaut dynamically intact. In effect, what these

runs demonstrate is that these events will occur, and that additional stress (fatigue, in these runs) contributes to the occurrence.

This effort has been continued in the two-man cabin program. In the recent 30-day flight only one illusion was reported by one subject--this illusion being auditory and at a very minor level. Interestingly enough, it occurred while the other subject was asleep, a situation with greater isolation and sensory deprivation than the remainder of the day. The paucity of illusory events might be attributed to the greater psychological reserve of men in the crew situation, (or better psychological nurturance) though such a conclusion is quite premature.

For the two-man cabin program, a new element in the analysis of dynamic behavior has been initiated. Members of a crew interact, and this interaction can effect both operator reliability and system reliability. One of the clinical psychologists in my group has adapted an objective observational technique for scoring interpersonal interaction in the cabin situation. A schedule for systematic observation and scoring was followed, using the Bales Interaction Process Analysis technique. In addition, a pre- and post-flight battery of psychological tests were administered. An unpublished, preliminary report (37) of the results from this first flight has been completed.

This study was directed towards two objectives: (a) the relationship between individual personality characteristics and crew interaction; and (b) personality changes occurring as a result of the stress of the flight. Dr. Hagen, who carried out this part of the program, reached several

conclusions. First, though there were many areas of similarity, the subjects had significant areas of difference in personality. Second, each of the two men contributed unique components to the maintenance of crew equilibrium, and these components were measurable. In particular, they developed adaptive techniques to compensate specifically for their personality differences. Third, the external elements of the situation, the simulator and its malfunctions, the psychomotor apparatus, the regular work schedule and other functional assignments all made major contributions to the maintenance of crew equilibrium. And fourth, both subjects show meaningful changes in personality as a result of the flight. For one subject the changes were small. For the other, the changes were quite large. Several hypotheses can be developed from this first flight. These hypotheses will undergo testing in future flights.

In any event, it is clear that the approach used in the first 30-day run makes a valuable contribution to the analysis of crew problems. It will not really be too long before space medicine will be asked questions about crew structure. Let us hope that, through these studies, it will be possible to give some of the answers.

There is also a bonus from this preliminary study. We had two psychologically different subjects. We got different degrees of change in personality characteristics as a result of the flight. We cannot, of course, label either of these "good" or "bad." But "different" is the first step to demonstrating that personality characteristics are a meaningful part of

selecting astronauts. I'm sure most of us feel this is an obvious truism, but there have been far too few empirical demonstrations of its contribution.

The study of dynamic aspects of behavior is being carried out in anticipation of the time when these problems will assume more immediate importance than they do now. At present, there are more difficult obstacles to manned space flight. It is possible that untoward incidents may occur. There are indications that these can be minimized or treated by rather simple, straightforward procedures. Selection for psychological adaptability for space flight, which has been considered in detail by Flinn (31), may be a greater problem in the future. At the present time, I do not regard it as one of the more significant selection variables. The orientation of this section of the paper reflects these points of view.

## SUMMARY

In this paper, I have described three major elements in the research on the psychophysiological problems of manned space flight at the School of Aviation Medicine. The unifying concept presented in the introduction provides a structure within which multi-discipline programs can function. Because the concept provides guidelines, each of us knows what kinds of participation are required. More time has been devoted into this paper to how we are approaching the questions than to results. There are still more problems than answers. In the hypodynamic study, for instance, we identified

several significant elements which need to be studied. In the space cabin program, we are making some headway on proficiency problems and on at least two aspects of dynamic behavior.

There is a great deal more work to be done. There are gaps in the problems we have been studying which need to be filled. Exciting projects are on the horizon. In the coming year, we hope to do more on the hypodynamic problem. We are getting under way on a very operationally-oriented program in bioelectrical techniques for assessing the functional state of man in space. We will continue to support the space cabin program. This paper is essentially an optimistic progress report. Next year's progress report should contain more answers and equal optimism.

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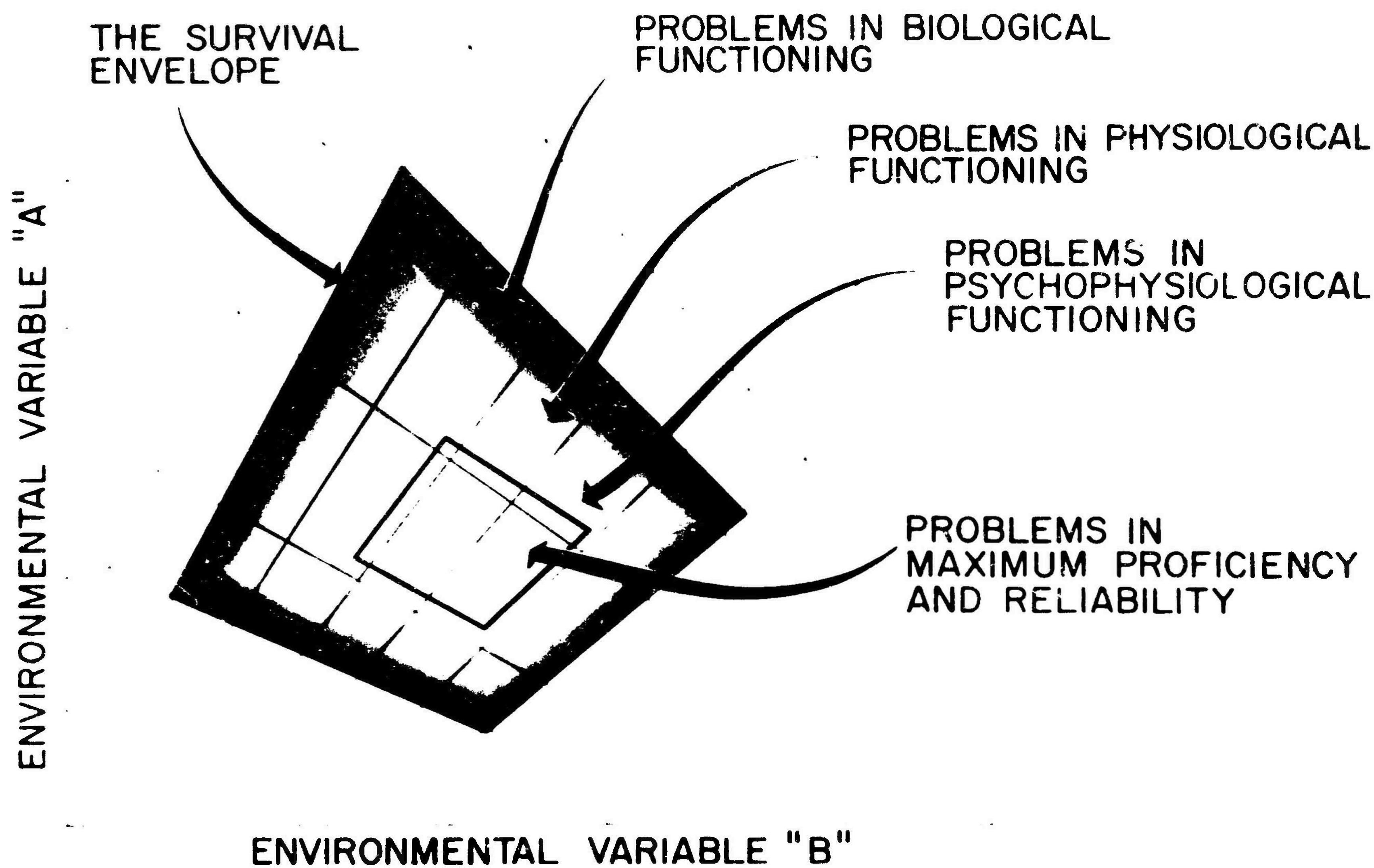


FIGURE 1

A schema for conceptualizing multi-disciplinary approaches to problems of manned space flight. The interaction of physiology and psychophysiology are illustrated in the concept.

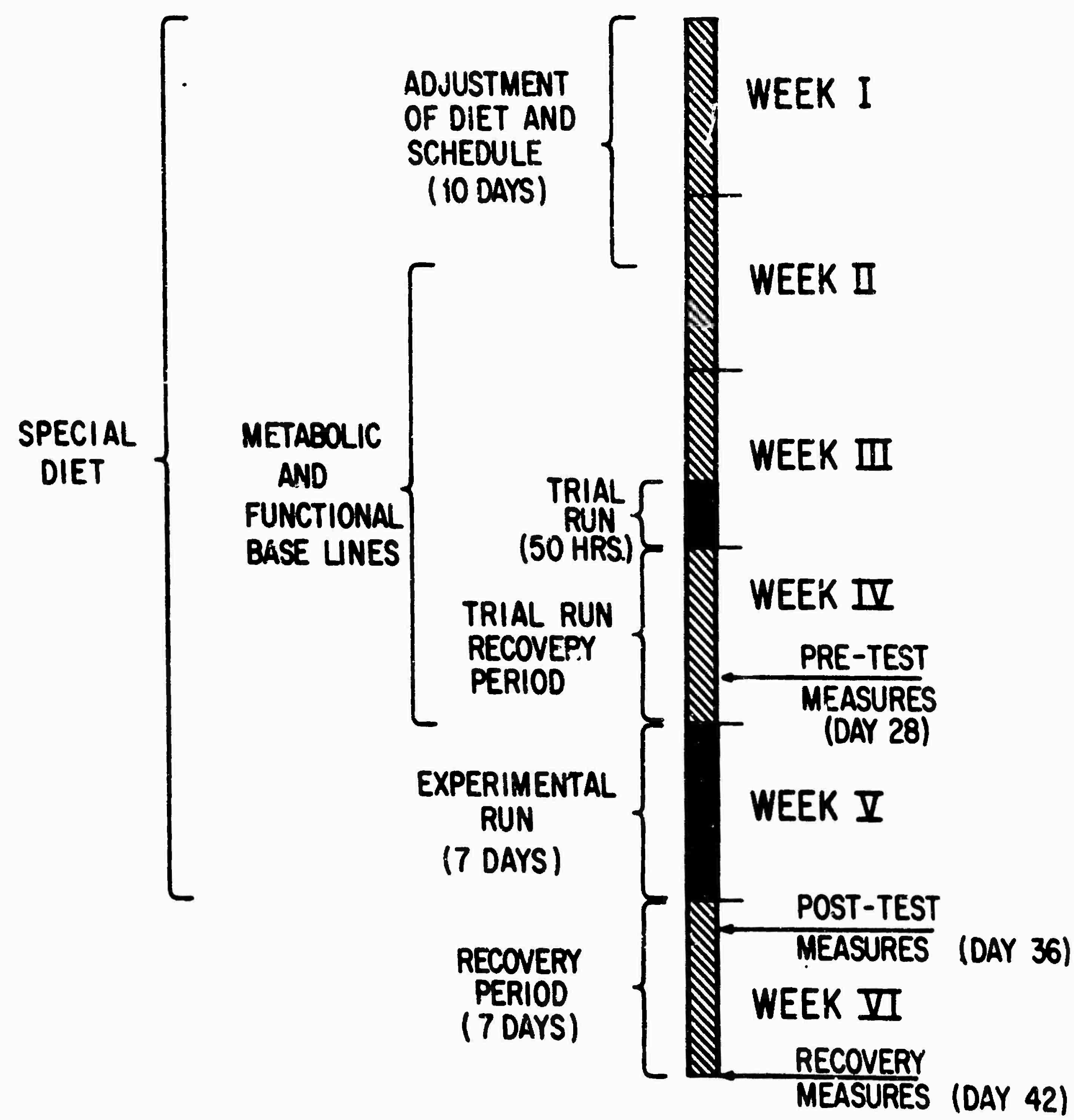


FIGURE 2

Schematic representation of the schedule for the hypodynamic experiment, by weeks. Black areas show periods of immersion.

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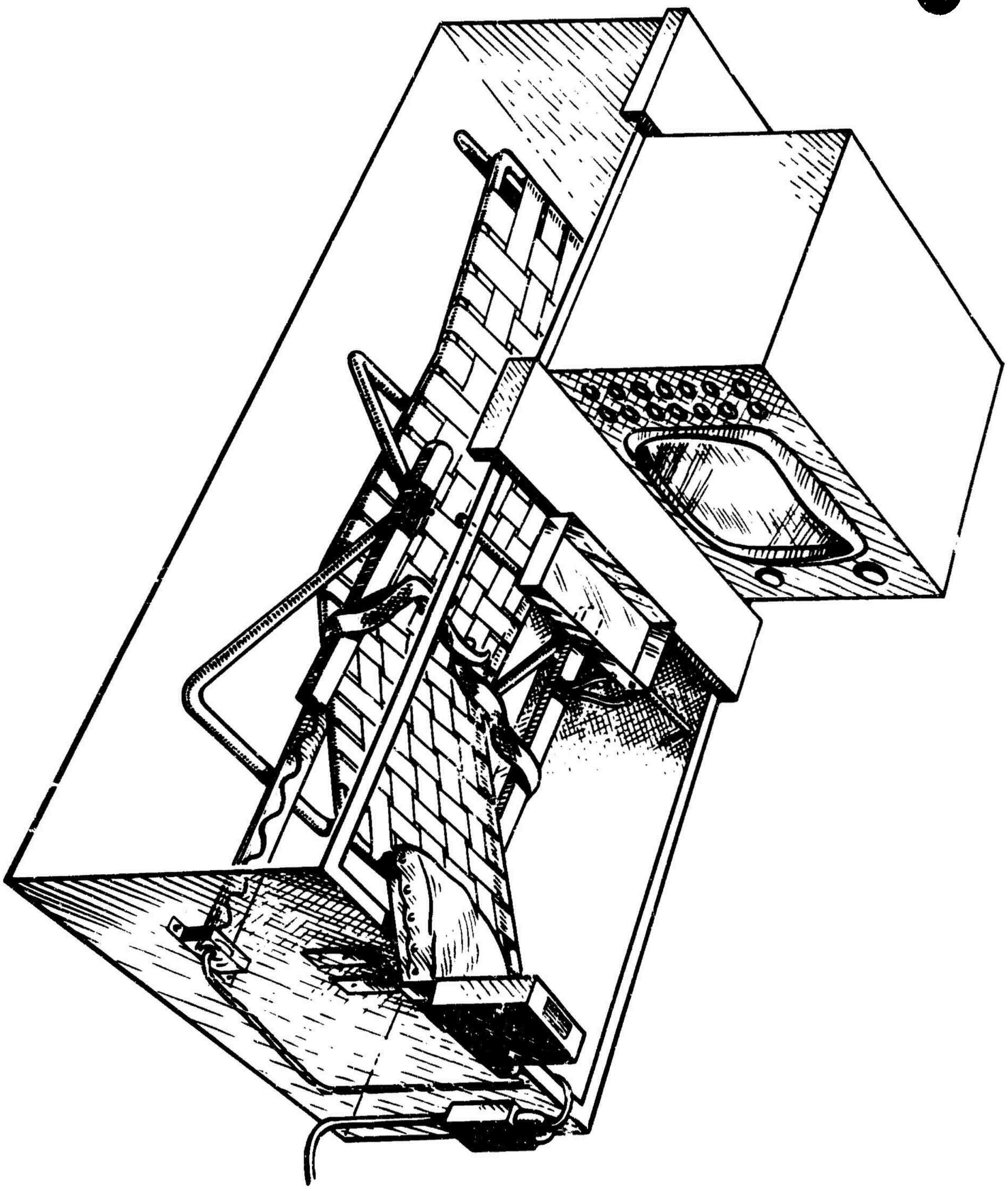

FIGURE 3

Photograph of the immersion tank showing the couch and heater inside, controls for the psychomotor tasks mounted on the couch armrests, and the task console and feeding trays above.

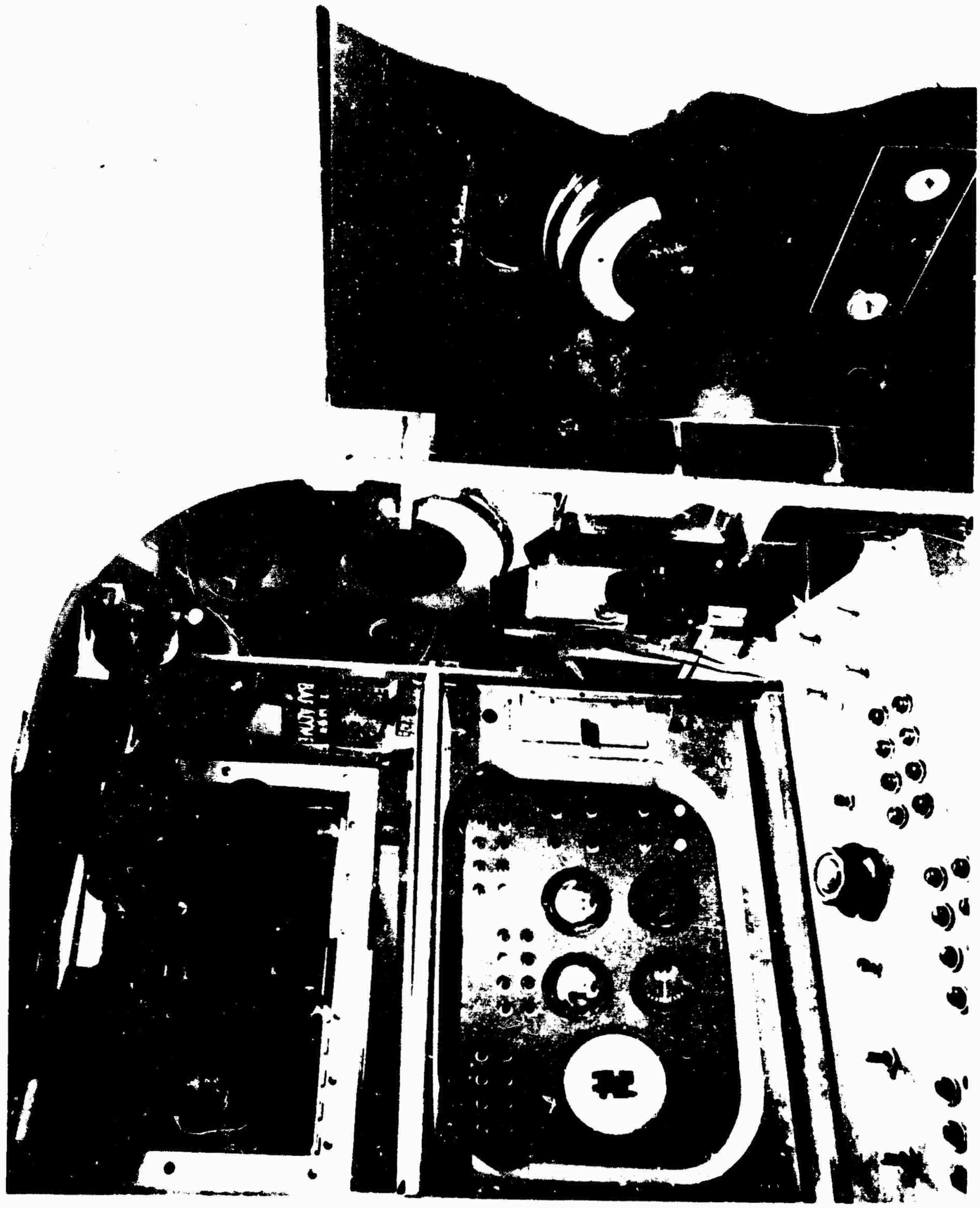

FIGURE 4

Photograph of the operator system in the SAM one-man Space Cabin Simulator. The display was present by closed circuit TV and is shown above the controls, which were grouped on a sloping panel within arm's length of the subject.

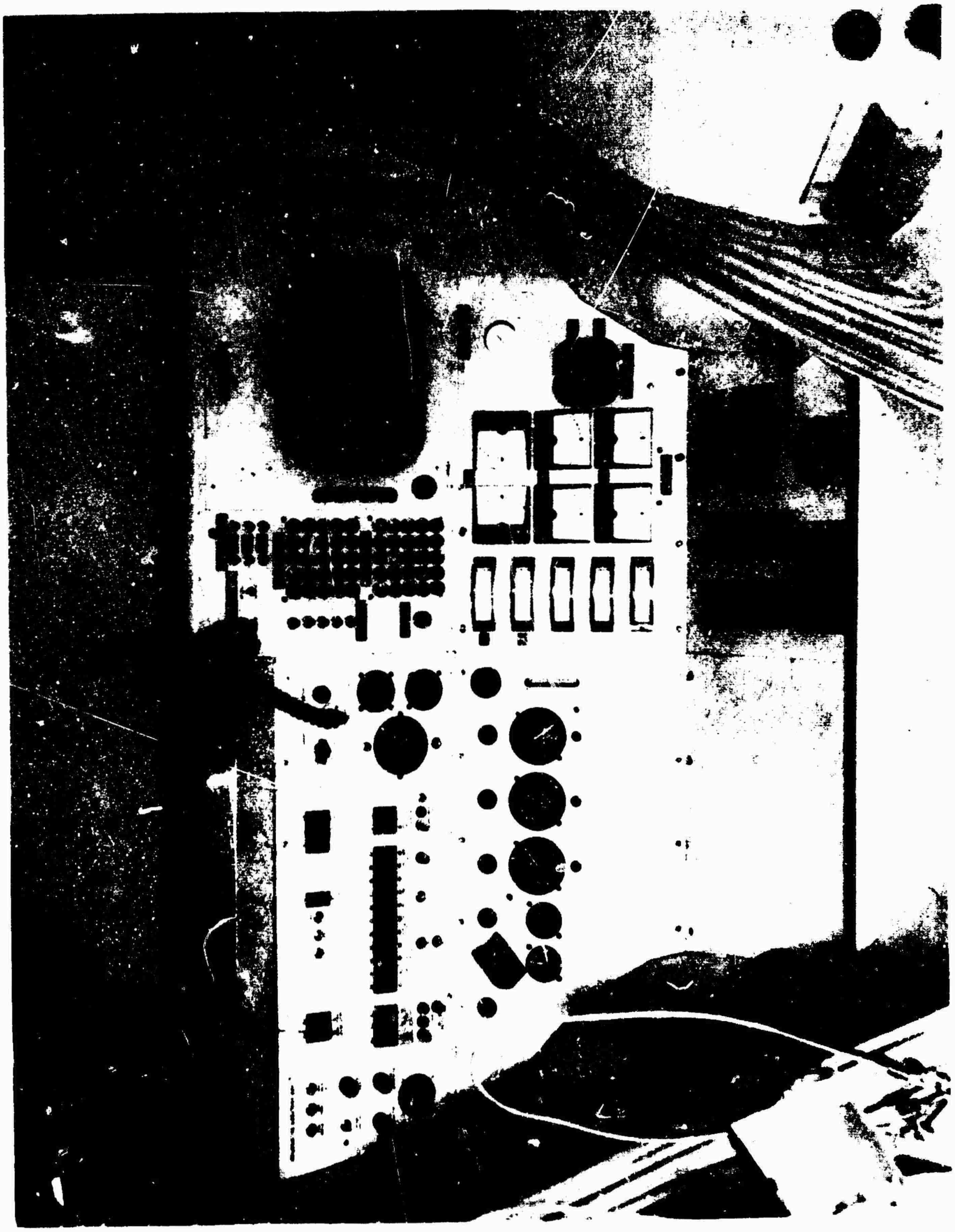

FIGURE 5

Photograph of the operator's station in the SAM two-man Space Cabin Simulator. Displays and controls for the psychomotor system are on the left. Displays and controls for the environmental monitoring and control system are on the right. Though there is space for two men at this station, each system is basically a one-man operation.

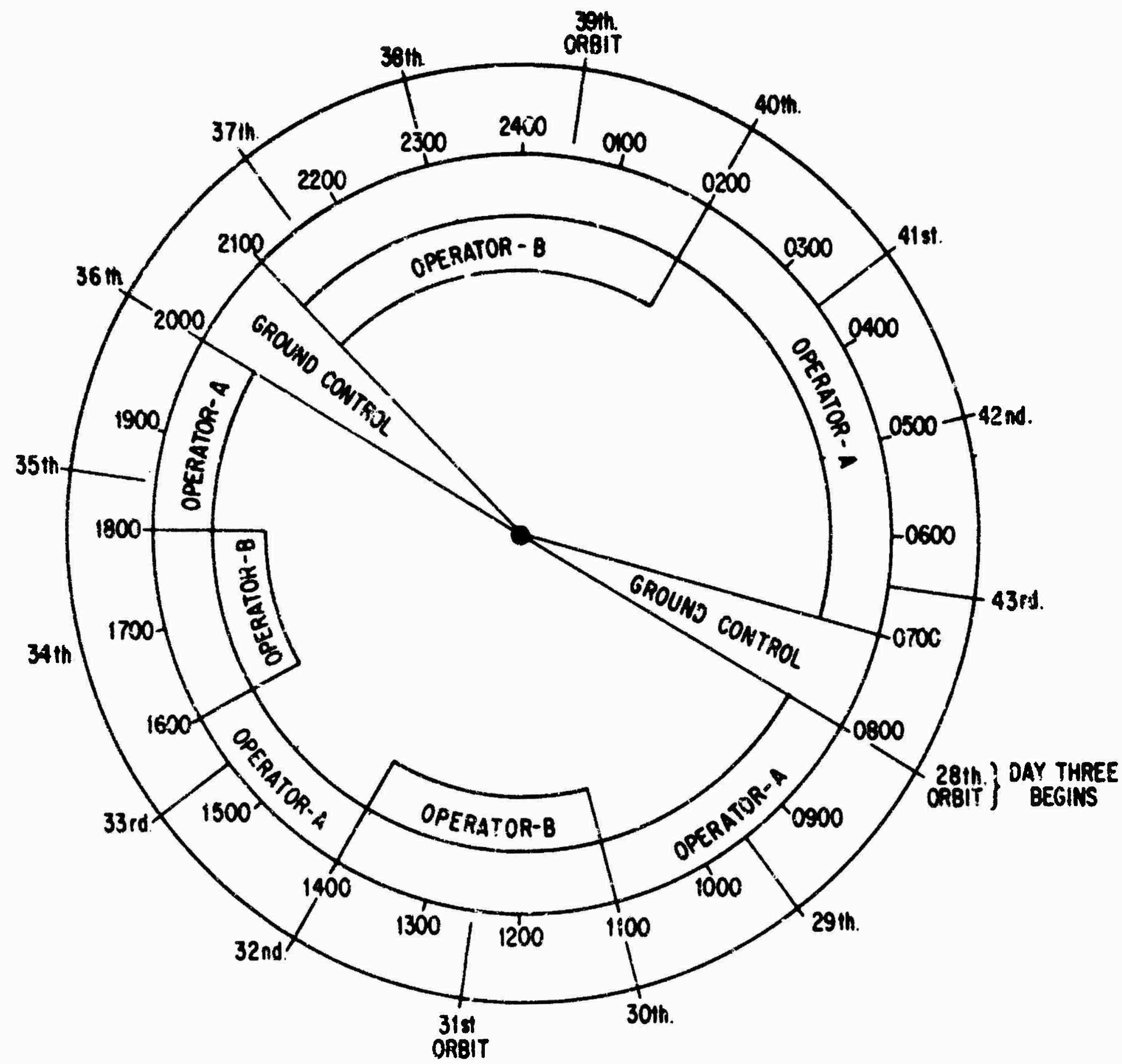


FIGURE 6

Schematic representation of a 24-hour period of the first 30-day flight in the SAM Two-Man Space Cabin Simulator. The work schedules for operator A and B, shown in the inner circles, were reversed on alternate days. Orbits for the simulated mission are also shown. The ground control periods were one-hour blocks when the psychomotor system was unmanned.

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LECTURES IN AEROSPACE MEDICINE

BIOLOGICAL SYSTEMS IN SPACE VEHICLES

Presented By

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Research Biologist

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School of Aviation Medicine

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BIOLOGICAL SYSTEMS IN SPACE VEHICLES

by

J. N. Phillips, Jr., Ph.D.

The preceding speakers have talked to you concerning the participation of man in space ventures and missions. Man's ability to exist in closed systems for extended periods of time has been adequately proven by experiments in space cabin simulators. At times during these experiments, conditions have been somewhat trying and man has shown that he is capable of remaining healthy and functionally efficient only when his environment is able to adequately supply him with necessities. A simple, yet obvious, observation has been that the performance efficiency level varies directly with the level of reliability and adequacy of the life support system. This generalization will undoubtedly be applicable to real space travel and space habitation vehicles as well. It behooves us, therefore, to examine the habitability status of space vehicles as we now know it and to ascertain what must be done to expand our knowledge and capabilities for future extensions of space travel and explorations.

I shall indulge a small license in the title of this presentation. In the ensuing discussion, I will consider satellite or planetary habitation structures space vehicles as well as missiles actually traversing

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NOTE: This manuscript reflects the views of the author and should not be considered official Air Force policy.

space. This is deemed justifiable because, excepting an actual propulsion system, any habitable structure we will be able to place on any celestial body in our solar system in the foreseeable future will require attention to identical life support parameters as those for a moving space vehicle.

This discussion will be limited to considerations of non-human biological components of space vehicles.

Further ground rules must be declared to set the frame of reference. For this purpose the following definitions will be arbitrarily established:

1. A space vehicle will be considered as both a moving or a stationary man-habitable structure.

2. A space vehicle as defined above will be considered to be a closed ecological system from the biological viewpoint.

3. A closed ecological system will be considered to consist of man and necessary associated life support systems, both animate and inanimate.

4. To be suitable for space utilization, an ecological system must be biologically closed, but may be thermodynamically open.

5. A life support system is defined as one which supplies man's basic biological requirements for a non-toxic breathable atmosphere, energy input in the form of edible food, removal or recycling of waste materials and stochiometric balancing of his respiratory quotient.

6. Life support systems are of two types, namely, non-regenerative and regenerative.

7. A non-regenerative life support system is one which has a definite utility time and which must be placed <u>in toto</u> aboard the space vehicle at the start of the mission.

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8. A regenerative life support system is one which has an indefinite utilization time and which continues to supply life support through recycling and re-use of a limited amount of initial fixed chemical energy.

A more detailed consideration of man's basic biological needs will be instructive and apropos. First, as defined previously, man requires a non-toxic breathable atmosphere. By this we mean an atmosphere which contains no or minimal quantities of toxic or noxious gases or volatile organic compounds. Of particular concern are concentrations of oxygen, carbon dioxide and carbon monoxide. Oxygen must be continually supplied for man's oxidative metabolism from which he derives energy and with which he builds, maintains and repairs his cells and tissues. This need may be illustrated in simple fashion by Figure 1 which shows the chemical balance in the metabolism of one mole of a simple carbohydrate substance such as glucose. It should be noted that, for the well being of man, carbon dioxide may be considered a toxic contaminant which must be either removed entirely or reduced to very low concentration levels.

The second basic requirement is for a fixed energy source in the form of edible food. For overall long range physiological well being, the dietary intake must contain adequate amounts of protein, carbohydrate and fat, and, on the average, in such ratios that around 1800 kcal per day is available from combustion or metabolism. Best nutritional balances indicate a need for 1.07 gm. of fat and 2.67 gm. of carbohydrate per gm. of protein oxidized, with approximate minima of 75.66 gm. of fat plus

188.79 gm of carbohydrate plus 70.71 gm of protein being required to satisfy the ratios for a total of about 1800 Kcal per day. Metabolism of such a diet would consume about 388 liters of oxygen, would liberate about 328 liters of carbon dioxide, and would lead to excretion of approximately 11 gm of nitrogen in the urine. These measurements, made by Dr. B. E. Welch (1960) and his staff, are for an almost sedentary metabolism allowing only minimal physical activity in a space cabin simulator. For a man engaged in light activity these figures, according to Clamann (1959), go up, as shown in Figure 2, to 520 gms of food intake plus 602 liters of oxygen plus 2200 gms of water resulting in a total excretion of 60 gms of waste solids, liberation of 499 liters of carbon dioxide and reappearance of 2540 gms of water. It will be noted that the water output is 15.45% higher than the water intake. This excess is called metabolic water and will result, from a completely closed system, in net water accumulation. When projected over a very long mission profile, this net accumulation of water may dictate necessity for a physical means of breaking water down to its constituents for recycling as primary input materials.

The next provision which must be made concerns either removal of accumulated waste materials or recycling of the materials by biological and/or physical breakdown to simple chemical substances. Such substances would then be reintroduced to the system as primary chemical input.

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Various means have been proposed for removal of man's wastes so that the entire system does not become autotoxic. These range from simple jettisoning outboard to firing back into earth's atmosphere in small rockets to freezing and storing in microbe-proof containers. Sound and serious objections can be raised against all of these proposals. Thus, the only apparent feasible procedure is to recycle these materials in some way so that they do not accumulate. Again a number of means have been suggested ranging from purely physical treatment such as incineration to combination treatments consisting of part physicochemical plus biological digestion to complete biological recycling.

Finally, suitable means must be found to bring about a favorable stochiometric balance between man's respiratory quotient and the assimilatory quotient of the other components of the closed ecological system. This, of course, is related directly to the requirement for removal of waste gases and replenishment of oxygen. Perfect respiratory quotient/assimilatory quotient balance requires that there be a 1 to 1 net exchange of carbon dioxide for oxygen.

There is no doubt in my mind that for short-time space operations, the human requirements may be best met by an expendable or non-regenerative system, i.e., by consumption of required materials from static sources plus absorption and/or accumulation of waste products. For operations of about one month or less, we already have the capability of sustaining the human organism in this fashion as shown by the space cabin simulator work reported by Dr. Welch (1960). However, the breakeven point in time

at which a regenerative system becomes preferable is not now definable. Each new series of experiments changes this point in time. It is possible that this figure will be still changing at the final moment before launch of man's first long mission space vechile.

In the thinking pattern of the biologist, a regenerative system is a closed ecological system modeled on earth's total biological population groups among which exchanged gases, foodstuffs, and wastes are balanced by the action and interaction of many microbial types. Such a balance yields a materially closed system which is maintained in a dynamic state by light energy alone. Thus, the most feasible attack on the problem of duplicating such a balanced system in a small space is predicated on proper selection of organisms and conditions to allow us to, in effect, miniaturize the balanced biological earth.

We must recognize, however, that even earth conditions are neither theoretically ideal nor are they steady-state conditions. Man, the dominant species, is continually altering the balance as a result of his activities. Therefore, a perfectly balanced ecological system is an idealized or limiting situation which we may strive to construct and even approach, but which we should not seriously expect achieve.

As scientists looked about in search of means and methods of achieving a closed system, they overlooked for a long time the one biological system of proven reliability and known capability to accomplish all the necessary provisions for man's space-craft habitation. The

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system to which I am referring is green plant photosynthesis. Whether embodied in the chloroplasts of higher plants or in the single cells of simpler forms, it is a piece of biochemical machinery carrying on what, to me, are easily the most important and fascinating series of chemical reactions taking place on earth. Our researches have told us a great deal about stepwise events and reactions contributing to the makeup of this machinery, but to date have not told us much about overall management of the system. Thus, it seems rational to direct our researches toward learning how to select and manage this machinery to best accomplish the task presently at hand.

Let us now consider how we may best use photosynthesis to accomplish our purposes. It must be borne in mind that in any plant, photosynthetic activities are integrated with a total metabolism system whose primary objective is production of more plant tissue. Accomplishment of oxygen production is purely a coincidental matter from the plant's standpoint. Photosynthesis is carried on in the higher plants, principally in the leaves, by chloroplasts. These small structures are rather severely restricted by spatial orientation in the leaf. This plus other restrictive factors causes photosynthesis rates and efficiencies to fall generally short of rates and efficiencies achievable by single free cells such as are found in a number of genera of the algae. Among all known photosynthetic organisms, the algae have the highest intrinsic rates of photosynthesis and growth. This plus a number of other characteristics

comprises a spectrum of compelling reasons why the principal organism of choice around which to construct a closed ecological system must be a unicellular alga. Basic characteristics of the algae were discussed one year ago during the 1960 Lectures in Aerospace Medicine series by Professor Jack Myers. I shall not go into these basic considerations on grounds of redundancy, but rather shall discuss current research here at the School of Aviation Medicine and our present status of capability as related to gas exchange, food production, waste recycling, and R.Q./A.Q. balancing.

## Gas Exchange Studies

These are obviously studies of the first order of importance to biological management of life support logistics. The basic assumption is: Man takes in oxygen and liberates carbon dioxide. For simplicity, we assume that in this process there is a 1:1 molecular ratio in this exchange. If we now illuminate a photosynthetic biological system such as a green alga suspended in an appropriate mineral salts medium, we can obtain precisely the reverse net reaction, i.e., one molecule of carbon dioxide taken up in photosynthesis is exchanged for one molecule of oxygen liberated. Concurrent with this exchange, plant cell material is synthesized and growth of the cell occurs. As a consequence of growth and cell multiplication, a point is reached at which illumination or light energy available becomes a growth limiting factor due to mutual shading by the cells in suspension.

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This mutual shading problem is the consequence of growth continually crowding more and more cell material into a constant volume as shown by Figure 3. The absorption of light in such a suspension of cells very closely follows mathematical predictions which may be made by combining Lambert's and Beer's laws of absorption, extinction and attenuation of incident radiant energy.

Lambert's equation predicts that radiation passing through a homogeneous absorbing medium will be reduced in intensity by the same fractional amount in equal succeeding portions of its path. Thus, if the intensity is reduced by half in the first centimeter, it will be reduced by half again in the second centimeter, and so on. If $dl$ represents layers of infinitesimal thickness, $I$ the intensity at any point along the path, and $\alpha$ (alpha) the fraction by which absorption reduces the intensity in unit length of path, then

$$-\frac{dI}{dl} = \alpha I, \text{ or integrated}$$

between the thickness limits $0$ and $x$, it gives the ratio $Io/Ix$ of radiation before, to that after, passing through thickness $x$, or

$$\log_e \frac{Io}{Ix} = \alpha x \text{ and converting to}$$

common logarithms we obtain

$$\log_{10} \frac{Io}{Ix} = Kx$$

Alpha in these expressions is the well known absorption coefficient and

$K$ is the extinction coefficient. When this expression is now combined with Beer's law which predicts that absorption of radiation is closely proportional to the number of particles per unit volume of suspension, whence

$$\alpha = \mu c, \text{ and}$$

$$K = kc, \text{ then we obtain an}$$

expression which precisely describes the extinction and absorption of light by a growing algal suspension:

$$\log_e \frac{Io}{Ix} = \mu cl, \text{ or}$$

$$\log_{10} \frac{Io}{Ix} = kcx.$$

If experimental data obtainable from growing algal cultures are now substituted into the combined Beer-Lambert equation, we obtain an experimental plot showing light absorption with increase in cell concentration. It can be easily observed that at some concentration all the light will be absorbed by the suspension. The consequence of further cell growth is that an ever increasing fraction of the algal cells are in the dark most of the time. Under these conditions, the population eventually becomes oxygen-demanding rather than oxygen-producing. Extensive experimentation has shown that this limitation may be compensated for by illuminating the cell suspension in a thin layer of film and/or by vigorous agitation of the culture liquid. Unfortunately, the surface area required for exposure of the cell suspension necessary to support one man in several hundred square feet and the weight of such a system would be on the order of one ton. Obviously, these are

ridiculous parameters for inclusion in any sort of space vehicle or habitation structure. Discovery of the ability of the algal cells to integrate light intensity times time of exposure led us to examine possibilities of reducing the size and weight of a man-support unit through intermittent exposure of the cell suspension in a thin film to a continuous light source. The theory here is that if the algae can approach the efficiencies, under these conditions, which may be achieved under conditions of continual illumination, then we might reasonably hope to reduce the size and weight of a one-man support unit. Here the design and engineering of the culture vessel become parameters of prime importance. The result of these considerations is the apparatus shown in Figure 4. We have named this the "duo-cone" culture vessel for obvious reasons. The culture suspension is held in the lower or reservoir portion of the vessel from whence it is pumped at low pressure and high flow rate to the top of the conical section. This section consists of two transparent cones separated by a gas space and illuminated from underneath by circular fluorescent lamps. The cell suspension flows in a film over the upper surface of the inner cone exposing the algae intermittently to the light source. The cycling rate is such that the entire culture volume of 20 liters makes the physical circuit from reservoir to reservoir in 54 seconds. We have selected an alga whose optimum temperature for growth and photosynthesis is identical with the operating temperature of the culture

unit. Although we have carried out relatively few experiments with this unit to date, performance data indicate that the net thermodynamic efficiency of the unit is better than 70% of the efficiency achieved by continual illumination of a thin film of cell suspension. Moreover, the data to date show that we can certainly cut the size of the necessary unit for 1 man support by a factor of at least 100 and the weight of the required cell suspension from 2000 to 250 pounds. We have by no means reached the maximum performance level of which the algae and apparatus are capable. Even the capability achieved to date make feasibility of photosynthetic gas exchange no longer a matter of conjecture or extrapolation.

Gas exchange studies will certainly continue toward the aim of indefinitely supporting man in a truly closed environmental system. Preliminary experiments carried out here at the School of Aviation Medicine and others now in progress within the industrial aviation community have taught us that man can indeed be supported in this manner. An even more important consequence of these studies has been to teach us that control of such systems is contingent upon a thorough knowledge of the basic biology of the components of such systems.

Waste Recycling Studies

The concept of the biologically closed ecological system obviously brings to mind the question of disposition of man's waste products. Very little in the way of precise data are available to describe current efforts at duplicating, accelerating and miniaturizing nature's

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microbiological recycling scheme. Such studies are obviously extremely complex and difficult to manage. Advancements to date include miniaturization and acceleration of conventional bacterial processes such that almost total reduction of biological oxygen demand of the daily waste output of one man can be carried out in less than six hours in an apparatus of small size, weight and power input requirement. Concurrently, studies are under way to enable us to grow excess algae on human wastes for production of enough oxygen to supply the demands of the bacterial process. The final combined products of the bacterial and algal actions on human wastes will be simple chemical species which are fed back into the gas exchange cycle.

Food Production Studies

As a consequence of the growth of algal cells in the gas exchanger, a point is reached where the algal population must be either continually or intermittently harvested. Since this harvested fraction of cells represents a considerable fortune in fixed chemical energy, it was realized that some useful disposition must be made of these cells. Chemical analysis reveals that, when the algae are grown in a medium rich in fixed nitrogen, the harvested cells contain a high percentage of their total weight of protein. This protein contains all the amino acids known to be essential in human nutrition except the sulfur-containing ones such as methionine, cystine and cysteine. If, on the other hand, the algae are grown in a medium in which fixed nitrogen is severely restricted, the cells produced contain a high percentage of unsaturated fat. Thus, for

no additional power or weight demand, the algae produce enough protein and/or fat to adequately supply the total daily demands for these substances in man's diet.

One problem of man's utilization of algae for food is his inability to digest cellulose, the material of the algal cell wall. Partial circumvention is provided by conventional cooking methods. However, in the event that cooking is not possible due to fuel and/or power input demands, some means must be found to break the cell wall so that man's digestive enzymes can reach the inner cell contents. A number of methods are adequate including disruption of the cell walls by sonic or ultrasonic vibrations, enzyme action and mechanical shearing forces. Which method to use is now being decided on the basis of comparison of required weight, space, time and energy input necessary by each of the methods to achieve 80% or more of cell wall destruction.

Balancing Man's Respiratory Quotient

A well known fact about man's respiration is that the ratio of oxygen required to carbon dioxide liberated is a function of the heat of combustion of the food being utilized in metabolism. When, for example, the food is largely protein, the respiratory quotient (R.Q.) will be low and when fat is metabolized the R.Q. will be high. The discovery that algal cells can be manipulated in such a way that they produce protein or fat as a function of fixed nitrogen immediately suggested a method of balancing man's R.Q. by adjusting the assimilatory quotient (A.Q.) of the algae. The assimilatory quotient is the inverse of the respiratory

quotient. Thus, if the A.Q. of the algae can be made to exactly balance man's R.Q. at all times, the net exchange of oxygen for carbon dioxide may be held in a 1 to 1 balance. Such studies, now being conducted at the University of Texas under the direction of Dr. Jack Myers, are beginning to confirm the theoretical considerations on which they are based, and the current outlook is that we will, by careful manipulation of the algal cultures, be able to hold R.Q./A.Q. balance in our closed ecological system.

Other Studies of Importance

We are conducting a number of other studies on biological systems for inclusion in a closed ecological system for space travel. For example, we are studying the capabilities of vascular or higher plant species as gas exchangers and particularly as producers of dietary variety for man's use. Data to date are very encouraging and great hopes are held for participation of higher plants.

Another problem under investigation is concerned with effects of various microorganism contaminants in photosynthetic gas exchanger units. These studies are in their infancy, and data to date are subjectively encouraging even though only preliminary.

Specialized environmental effects of space, such as radiation damage of photosynthetic capacity and genetic stability are under intensive scrutiny.

Finally, it has been reported that algal cultures produce large quantities of carbon monoxide. We have been unable to corroborate such reports for healthy, actively growing cultures of a variety of algal species. It has been found that carbon monoxide production arises from pigment breakdown due to death and autolysis of cells when the culture is not kept physiologically vigorous and healthy.

In conclusion, let me now attempt to synthesize all the research now being carried out on closed ecologies into what we visualize the operation of the total system of systems will be as shown in Figure 5. This represents our ultimate aim consisting of a system biologically closed but thermodynamically open.

Less than ten years ago, such topics as have been discussed were considered "way out." Indeed, it has been only since successful launching of the first rocket satellite that use of the word "space" has become acceptable in polite scientific conversation. The ensuing few years have produced great advances it is true, but we are just now emerging from the stone age in terms of understanding the mechanisms and management of nature's billion and a half year's handiwork. Formidable as the task ahead seems, I am confident that we will solve the problems confronting us. The sobering thought remains with us all, however, that man is likely to learn how to manage nature before he learns how to manage himself.

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## METABOLISM OF ONE MOLE OF GLUCOSE

| GLUCOSE | + | OXYGEN | $\longrightarrow$ | CARBON DIOXIDE | + | WATER | + | ENERGY |
|---|---|---|---|---|---|---|---|---|
| $C_6H_{12}O_6$ | | $6\ O_2$ | | $6\ CO_2$ | | $6\ H_2O$ | | 3.75 KCAL/GM. |
| $\uparrow$ | | $\uparrow$ | | $\downarrow$ | | $\downarrow$ | | $\downarrow$ |
| FROM FOOD | | FROM ATMOSPHERE | | TO ATMOSPHERE | | TO TISSUES, INTESTINE, ATMOSPHERE | | TO TISSUES FOR BIOSYNTHESES AND TO HEAT |

RESPIRATORY QUOTIENT (R.Q.) = MOLES $CO_2$/MOLES $O_2$ = 6/6 = 1

$CO_2$ IS CONSIDERED TO BE AN ATMOSPHERIC CONTAMINANT

FIGURE 1 - Energy and Waste Gas Liberation as a Result of Metabolism of Glucose (M.W. = 180.16)

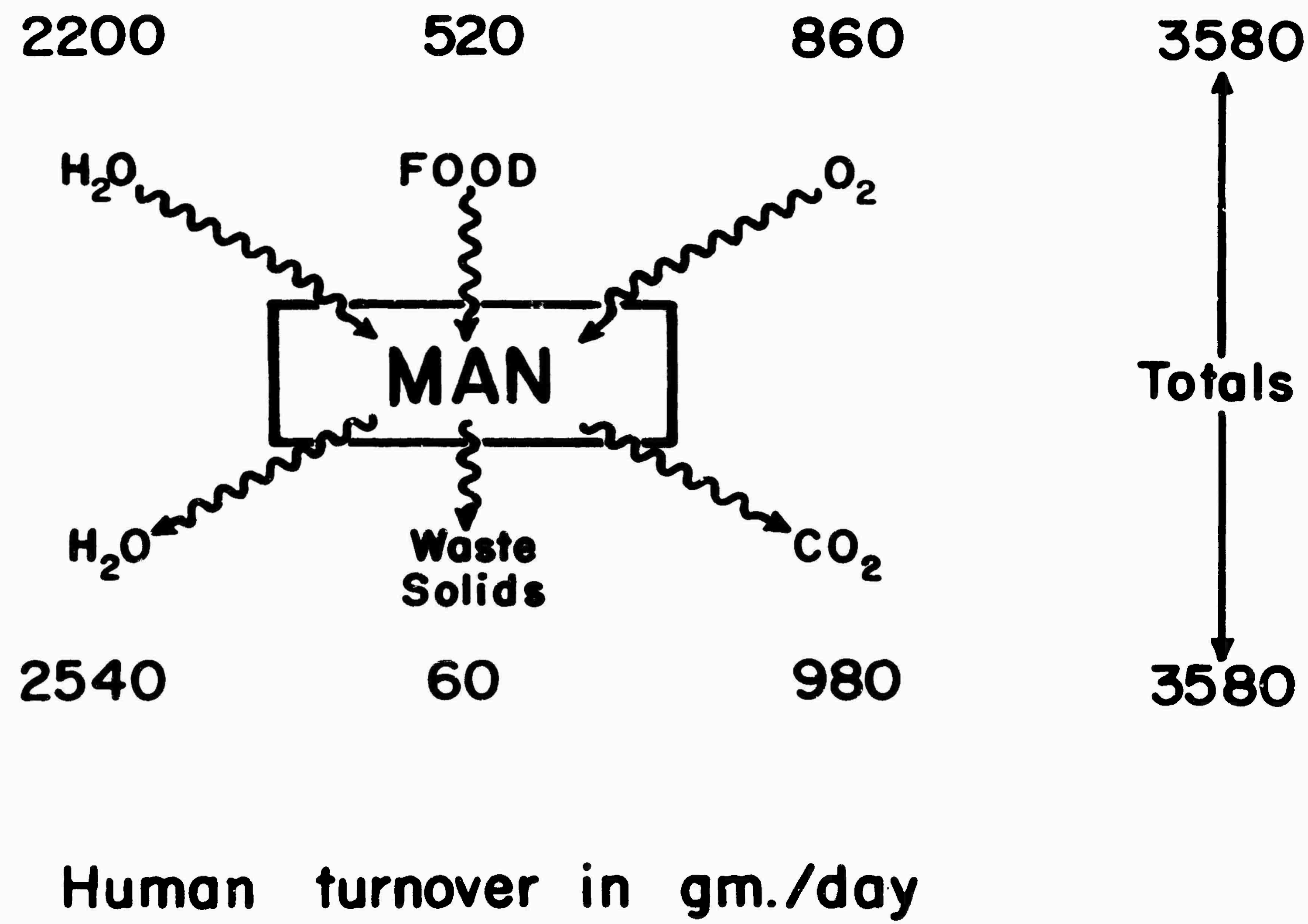


FIGURE 2 - Human Turnover in Grams Per Day (Myers, 1960)

LAMBERT'S LAW:

$$-\frac{dI}{dl} = \alpha I, \text{ OR INTEGRATED BETWEEN } \underline{o} \text{ AND } \underline{x}:$$

$$\ln \frac{I_o}{I_x} = \alpha x, \text{ OR}$$

$$\log \frac{I_o}{I_x} = Kx$$

BEER'S LAW:

$$\alpha = \mu c, \text{ AND}$$

$$K = Kc$$

COMBINED:

$$\ln \frac{I_o}{I_x} = \mu cl, \text{ OR}$$

$$\log \frac{I_o}{I_x} = kcx$$

PLOT OF LIGHT ABSORPTION BY A GROWING ALGAL CULTURE:

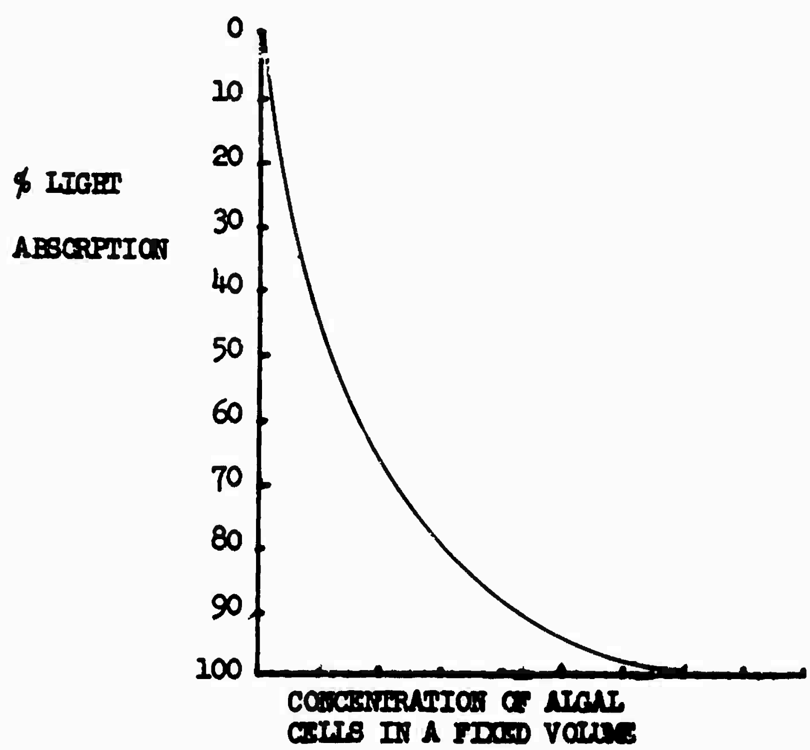


FIGURE 3 - Light Absorption by a Growing Algal Culture as Predicted by Beer's and Lambert's Laws

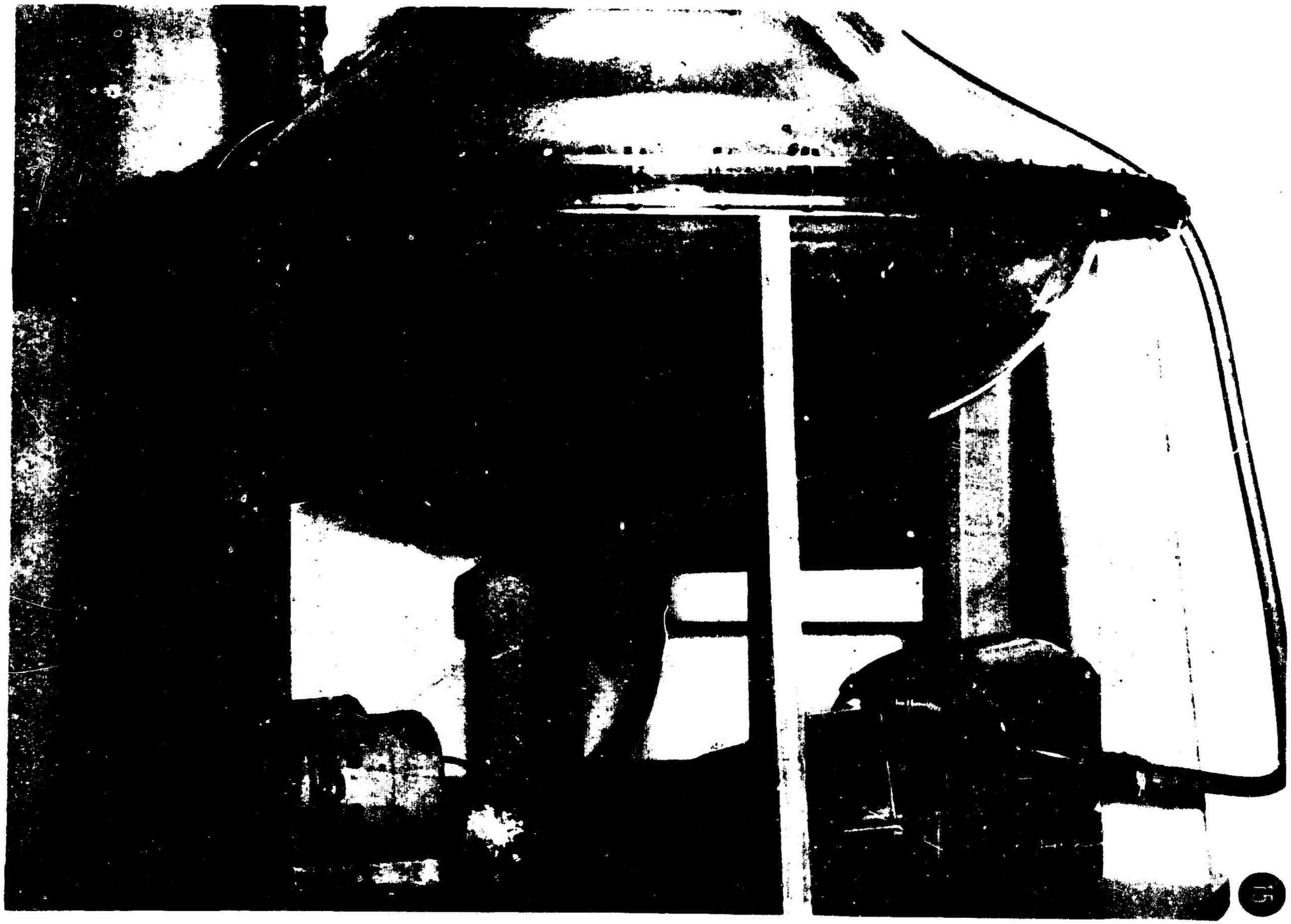

FIGURE 4 - The Duo-Cone Algal Culturing Apparatus. Illumination Provided by 3 "Circline" Fluorescent Lamps; Total Wattage Rating 94.

INTERRELATIONS OF BIOLOGICAL SYSTEMS IN A CLOSED ECOLOGICAL ENVIRONMENT

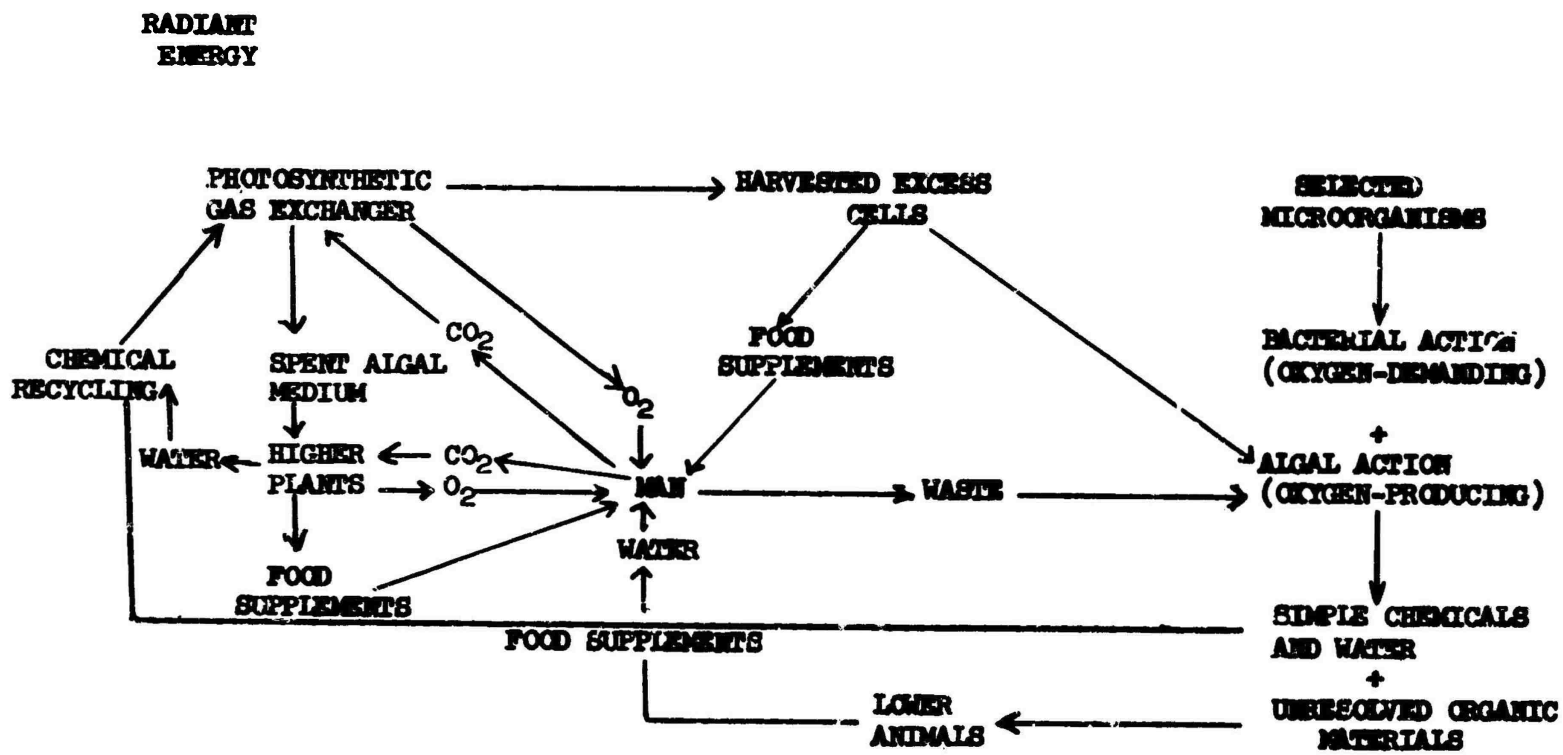


FIGURE 5 - Interrelations of Biological Systems in a Closed Ecological Environment

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# LECTURES IN AEROSPACE MEDICINE

# STERILIZATION OF SPACE VEHICLES:

# THE PROBLEM OF MUTUAL CONTAMINATION

Presented by

E. Staten Wynne, Ph.D.

Chief, Microbiology-Cellular Biology Branch

School of Aviation Medicine

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## STERILIZATION OF SPACE VEHICLES: THE PROBLEM OF MUTUAL CONTAMINATION

by

E. Staten Wynne, Ph.D.

Since the first satellite was launched, there has been a revival of interest in the origin of life and the possibility of the existence of life elsewhere than on the earth. In a recent stimulating article entitled "Origin of Life on Earth and Elsewhere," Calvin (1) has quoted Shapley (15) on the number of planets in the universe with environmental conditions capable of supporting cellular life similar to that on earth. Shapley has estimated the minimum number of stars in the universe at $10^{20}$, with perhaps one in a thousand having planets. This author further postulates that one in a thousand of the $10^{17}$ planets has the correct range of temperature variation, and one in a thousand of these possesses the correct size to retain quantitatively appropriate atmosphere. Finally, he estimates that of these latter $10^{11}$ planets, one in one thousand contains the proper atmosphere, including the elements C, H, O, and N. Thus one hundred million is the minimum estimated number of planets with environments capable of supporting life as we know it on earth. Furthermore, it is conceivable that forms of life based on silicon, nitrogen, or even anti-matter may exist (1).

There has been considerable speculation concerning the possibility of life elsewhere in our own solar system, especially on Mars. As pointed out by Sinton (16), the belief that life exists on Mars has been supported by observations that (1) dark areas spread from the

NOTE: This manuscript reflects the views of the author and should not be considered official Air Force policy.

polar regions toward the equator each spring and summer, coincident with the melting of the polar caps, and (2) some areas previously observed as invariably light have suddenly darkened. The supposed life on Mars has generally been considered to be plant in nature, although Lederberg (7) has cautioned that it may be entirely different from plant life on earth. Recently Sinton (16) has obtained direct evidence for the presence of carbon-hydrogen linkages by demonstrating absorptions in the infra-red at 3.43, 3.56, and 3.76 $\mu$. The last-named band was first considered anomalous, since it had not been observed in terrestrial plants; however, this author subsequently demonstrated it in the alga *Cladophora* and the lichen *Physcia*. This band is believed due to carbohydrate. Although Sinton states that the presence of these absorption bands does not constitute absolute proof of the presence of organic matter, they appeared in the spectra from four areas of Mars which are mostly dark, but were absent or weak in spectra from two bright regions. Since the dark areas of Mars shift location periodically, the evidence that they contain organic matter is certainly impressive--and on earth organic matter is associated with life.

As pointed out by Lederberg (7), the best approach to direct studies of the possibility of extraterrestrial life involves microorganisms, since they are (1) an early stage in the evolutionary process, (2) ubiquitous on our planet and probably any other planet containing life, (3) easily cultivated, and (4) best adapted to automation and telemetry in unmanned space vehicles. According to

Zhukov-Vereshnikov et al. (17), the principal task of cosmic microbiology is the study of microscopic forms of life on planets.

However, direct studies on the possible existence of extraterrestrial life would be seriously jeopardized, or even made forever impossible, by inadvertant contamination of celestial bodies with earth microorganisms deposited as a result of hard landings of space probes (2, 5, 7, 8, 11, 13). As pointed out by Davies and Comuntzis (2), one *Escherichia coli* cell, with a mass of approximately $10^{-12}$ gm and a generation time of 30 minutes, at the maximum (logarithmic) growth rate would require only 66 hours to produce progeny equal to the mass of the earth. It is believed that earth microorganisms might well multiply on Mars (2, 3, 5), or possibly even on the moon (2, 7, 8, 13). Such multiplication would not only interfere with determining the presence or absence of an indigenous flora, but by overgrowth might also jeopardize any possible use of extraterrestrial organisms for benefit of man (7).

Contamination of the moon with earth microorganisms would also jeopardize a most intriguing test of the panspermia hypothesis of Arrhenius, according to which spores drifted through space and seeded suitable planets. According to Sagan (12), early in its history the moon had a reducing atmosphere of secondary origin. During this time organic molecules, including amino acids, may have been formed by the action of ultraviolet light and diffused to the surface by gravitational forces. Sagan has estimated that perhaps 10 gm/cm$^2$ of organic matter was formed and subsequently buried by meteoric infall, thus

acquiring protection against the high day-time surface temperature and strong radiation flux developing after the atmosphere disappeared. In another paper (13), this same author theorizes that during that remote period when the moon had an atmosphere, microorganisms may have developed and been preserved beneath the surface with the buried organic matter.

Somewhat more likely is the possibility that, after virtual disappearance of the moon's atmosphere, any microorganisms impinging on the moon from space may have survived by being deposited in crevices (2, 7, 8, 13). Although the surface temperature is estimated to range from +100 C. during the day to -180 C. at night, it has been estimated that at a depth of less than ½ meter, the temperature range is 0 to -70 C. Although the ultraviolet radiation intensity on the surface of the moon is capable of killing all known microorganisms in a few hours, Sagan (13) believes that microorganisms just beneath the surface, and thus protected from ultraviolet radiation, would survive cosmic radiation for a few hundred million years. Having only a trace atmosphere, the moon has been envisioned as a trap for meteoroidal material (7), and is supposedly covered by a layer of cosmic dust (8). Since the likelihood of a persistent indigenous flora is remote, the presence of microorganisms in the "moondust" would constitute evidence for the panspermia hypothesis.

While it has been suggested that earth microorganisms might actually multiply if deposited in crevices beneath the surface of the moon (7, 8), even survival without multiplication could jeopardize a

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test of Arrhenius' hypothesis. Because of extremely low frictional resistance of the present trace atmosphere of the moon, it was recently stated by Phillips and Hoffman (11) that a single hard landing of a rocket could scatter bacteria over the entire surface of the satellite. As pointed out by Davies and Comuntzis (2), this possibility would be especially serious if a mammal were aboard, since there would be on the order of $10^{12}$ microorganisms present per kg of intestine. As the moon's surface is $4 \times 10^{13}$ m, the microorganisms from one splattered mammal might give rise to a serious degree of contamination, especially since the density of any organisms trapped from cosmic infall would not be expected to be great.

In view of these considerations, there has been a great deal of concern over the question of contamination of celestial bodies with terrestrial microorganisms (2, 5, 7, 8, 11, 13). Shortly after the launching of Sputnik I, the Council of the National Academy of Sciences of the United States adopted a resolution urging great care in planning lunar and planetary studies, in order to avoid biological contamination. The Council also requested the International Council of Scientific Unions to encourage evaluation of the possibilities of contamination and development of means of prevention. In response, the International Council of Scientific Unions established a committee on contamination by extraterrestrial exploration, also known as CETEX. A summary of the first meeting of this committee was published in Science (5) by the general assembly of the International Council.

The recommendations included the drafting of a code of conduct for lunar and planetary explorations.

It is interesting to note that CETEX has rejected the panspermia hypothesis on the grounds that solar radiation would destroy spores during transport through space. In answer to this objection, it has been pointed out that only a thin layer of matter would protect against the radiation (7). The committee also rejected the possibility of multiplication of earth microorganisms on the moon, on the basis that water could not exist in such a high vacuum, a viewpoint at variance with that of some investigators (2, 12). On the other hand, CETEX pointed out the danger of macromolecules from dead microorganisms serving as templates for "prelife" growths, thus interfering with studies of prebiotic evolution. The importance of contamination by organic matter has also been stressed by Davies and Comuntzis (2).

The possibility of contamination of the earth with microorganisms from a celestial body is no less worthy of sober consideration than the reverse. It is theoretically possible that microorganisms brought back from the moon or Mars might be capable of causing a new human disease. Lederberg (7) considers this possibility rather remote, since such a microorganism would have had no opportunity to develop adaptations for resisting host defenses. Nevertheless, this same author considers the possibility that human defense mechanisms have been evolved against terrestrial bacteria, and our capability might be much less against organisms lacking characteristic foreign proteins

and carbohydrates. Lederberg adds that at any rate, such organisms might constitute a nuisance in agriculture.

At first thought, it might appear that contamination of celestial bodies with terrestrial microorganisms would not constitute a practical problem, since any organisms in an unmanned vehicle would be destroyed in transit. However, it has been pointed out (2, 11) that organisms might easily survive. Ultraviolet radiation in space, while admittedly lethal to any known microorganism in a few hours, would only be effective against organisms on the outside surface of a space probe. Furthermore, vacua actually aid in preservation of microorganisms, although it must be admitted that no data are available on the effects of extremely high vacua, approaching that to be encountered in space. Finally, it has been pointed out that entry into the atmosphere of Venus or Mars would not necessarily result in a probe being consumed by heat (2, 7). The atmosphere of Mars is mostly nitrogen, with only a trace of oxygen, while that of Venus is chiefly carbon dioxide.

It would thus appear that rigorous measures are needed to insure the absence of viable microorganisms in a space vehicle prior to its launch. Methods suggested include sterile assembly, built-in sterilization, and terminal sterilization (2). Sterile assembly may be either aseptic or antiseptic. Davies and Comuntzis (2) considered the latter, e.g., the dipping of screws and bolts into a sterilizing solution before joining. However, aseptic fabrication of certain hermetically sealed components, using sterile parts, is a possibility

which should not be overlooked. Built-in sterilization might be of value in fabrication of certain components; e.g., paraformaldehyde might be included in plastic used for potting electronic components or insuring a tight seal of screws (11).

In any case, terminal sterilization, particularly of the interior of any space vehicle, appears essential. In the interest of preventing recontamination, it has been suggested by Phillips and Hoffman (11) that such sterilization be carried out at the last possible moment before launching. Suggested methods have included use of heat, radiation, and chemicals. It has been pointed out by Davies and Comuntzis (2) that approximately 20 percent of the components that go into payloads cannot be sterilized by heat. Phillips and Hoffman (11) have emphasized the practical difficulties involved in utilizing radiation sterilization just prior to launching. Furthermore, Davies and Comuntzis (2) found that transistors and mercury cell batteries would not tolerate sterilization by this method. For chemical sterilization, it would appear that agents active in the vapor phase are most feasible. Of gaseous disinfectants, alkylating compounds appear preferable, since it has been shown by Phillips (10) that the activity of this class of disinfectants against spores is relatively high. This worker compared the resistance of spores of *Bacillus globigii* to that of vegetative cells of *Micrococcus pyogenes* and *Escherichia coli*. The ratio of the resistance of the spores to that of the vegetative cells was from 2 to 6 for ethylene oxide, approximately 1000 for trichlorophenol, and

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about 10,000 for sodium hypochloride and a quaternary compound. The relatively higher efficiency of alkylating agents against spores was thought by this worker to be due to their interaction with any one or more of several groups on protein molecules (-COOH, -SH, -OH, and $-NH_2$).

In figure 1 are shown structural formulae of three gaseous alkylating agents: formaldehyde, ethylene oxide, and β-propiolactone. Formaldehyde, while effective, has the disadvantage of damaging materials and leaving a persistent film. β-propiolactone has been suggested as a substitute for formaldehyde vapor. This compound readily hydrolyzes to β-hydroxypropionic acid, and no deleterious effects on materials have been observed. In a field test of a 50,000 $ft^3$ building, and a disinfectant concentration of 5 mg/l, Hoffman and Warshowsky (6) were unable to recover spores of B. globigii after a period of two hours. With concentrations of two mg/l of less of β-propiolactone acting for fifteen minutes, Dawson et al. (4) observed complete inactivation of a number of viruses, including neurotropic, dermatropic, viscerotropic, and pneumotropic types. The agent was also effective against the rickettsia Coxiella burnetii (4). Hoffman and Warshowsky (6) have reported that this agent is about 25 times more effective than formaldehyde vapor, and around 4000 times as active as ethylene oxide. It is also noninflammable under ordinary conditions, since saturated air at normal temperature and pressure contains only about 6 mg/l. However, β-propiolactone lacks the high penetrating power of ethylene oxide, and also requires a relative humidity of 75 percent or more (6) for maximum effectiveness.

Ethylene oxide is generally considered the gaseous disinfectant of choice for space vehicles (2, 7, 11). The desirable features of this agent have been summarized by Phillips (9). Ethylene oxide penetrates closed paper envelopes surrounded by multi-layers of fabric. It is both water- and oil-soluble, so that organisms in either will be sterilized, provided depth is not excessive. This disinfectant is effective in the presence of organic matter and is not damaging to materials. Ethylene oxide can be used in the presence of air (9, 14), so that it is unnecessary to evacuate closed chambers before applying the agent. The gas is flammable, but is now available commercially in a non-flammable mixture with dichlorodifluoromethane and trichloromonofluoromethane (14). It is effective against viruses (2).

For the actual terminal sterilization of space vehicles, Phillips and Hoffman (11) have suggested use of 300-400 mg/l of ethylene oxide in a plastic bag enveloping the vehicle, its metal fairing, and if necessary, the third stage rocket. The latter should be disinfected in case it is intended to follow the vehicle into space. After exposure, the plastic would be cut away and the ethylene oxide gas surrounding the vehicle would disperse in a few moments. If the interior of the vehicle were also being sterilized on the launching pad, the disinfectant could be displaced by sterile air drawn through an appropriate bacteria-tight filter, such as one of cotton or spun glass. If necessary for cooling, sterile air could likewise be blown under the fairing. On launching, the fairing

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would, of course, be recontaminated, but it would act as a shield to prevent contamination of the remainder of the probe.

Prevention of contamination of hermetically sealed components constitutes a special problem. Sterile fabrication, making use of sub-units sterilized by appropriate methods, would be laborious. Obviously gaseous disinfection cannot be used, once sealing has been effected. It has been estimated by Davies and Comuntzis (2) that about 20 percent of the components that go into present payloads cannot withstand heat sterilization. Sterilization by radiation is feasible, but the same authors found that transistors and mercury cell batteries would not withstand a decontaminating dose of radiation. A great variety of hermetically sealed electronic components are currently used in space vehicles. Since bacteria inside these components could be scattered over the lunar or planetary surface following a hard landing of an unmanned prove (2, 11), studies on the actual bacterial content of the present components and their tolerances to sterilization are especially pertinent. Recently Phillips and Hoffman (11) reported that 13 of 62 capacitors and 6 of 41 resistors showed bacteria in the interior.

We have just initiated a study of the bacterial content of the interior of hermetically sealed electronic components used in space probes, as well as their tolerances to heat sterilization. These studies are carried out in a flexible film germfree isolator. Ethylene oxide in the commercially available non-flammable mixture with

halogenated hydrocarbons (14) is introduced into the isolator to effect sterilization of the working area and the exterior of the components studied. After 6-9 hours contact, the disinfectant is displaced by compressed air filtered through spun glass to insure sterility. The tools used to disassemble the components are sterilized inside the isolator along with the electronic devices themselves (fig. 3). Some units, such as carbon resistors, are easily crushed with mortar and pestle. Those encased in metal are opened by means of a jeweler's saw and pliers, and units covered with porcelain or ceramic generally require use of a hammer. To facilitate detection of any contaminating organisms which may be present, it is essential to expose all internal surfaces and to reduce all nonmetallic covering materials to a relatively finely divided state. Recently it was found that one capacitor approximately 2½ inches long by 1 inch in diameter contained, when completely unrolled, a surface area of about 50 square feet. Disassembling such a unit and immersing it in appropriate bacteriological culture media inside the isolator, with the hands encased in heavy rubber gloves (fig. 4), is no easy task.

In figure 5 are seen a number of types of capacitors; mylar, ceramic, paper, mica, and electrolytic. The name of these units signifies the type of dielectric used. The internal structure of a mylar capacitor is shown in figure 6. The waxed cover is easily removed by cutting or scraping, following which the foil and polyester dielectric may be unwound. In figure 7 is illustrated a paper

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capacitor with a hard outer surface which may be crushed to expose the interior. The foil and paper dielectric layers are then unwound for culturing. The internal structure of a mica capacitor is shown in figure 8. The molded plastic covering is crushed with mortar and pestle, and the thin sheets of mica separated like the leaves of a book. An electrolytic capacitor with metal cover is illustrated in figure 9. The interior consists of rolled layers of tantalum and paper impregnated with an electrolytic paste. In figure 10 are seen five types of molded carbon resistors and three types of wire-wound resistors (two fixed and one adjustable). For culturing, these components are crushed with mortar and pestle (fig. 11). A number of diodes and transistors are illustrated in figure 12. For sterility tests, these units are disassembled in several ways, depending on the type of covering material. Components with glass, molded bakelite, or plastic coverings are crushed with mortar and pestle. Metal-encased components are opened with cutting pliers and the interior crushed.

As indicated by Phillips and Hoffman (11), it is necessary to test the efficacy of the preliminary ethylene oxide sterilization of the exteriors of sealed components by immersing assembled units in culture media. Any cultures showing cloudiness should be checked microscopically for the presence of bacterial cells, streaked to agar plates for aerobic growth, and inoculated into fluid thioglycolate broth or other appropriate medium for anaerobic growths. An important part of the sterility checking is the inoculation of all negative

culture tubes to demonstrate lack of bacteriostatic action of the components. Pseudomonas aeruginosa is the test organism currently employed for this purpose in our laboratory. Preliminary studies with capacitors have demonstrated uniformly the efficacy of the ethylene oxide sterilization of the exteriors. Furthermore, of 56 capacitors tested, 3 were contaminated. Fifteen carbon resistors cultured yielded only negative results.

A number of components have been subjected to temperature-time regimens: 165 C for 2 hours, 140 C for 3 hours, and 121 C for 16 hours. The heat-treated components were then checked for performance. Four of five capacitors exhibited impaired performance after exposure to 165 C for 2 hours, and one after being subjected to 121 C for 16 hours. Five resistors were unaffected by any of the regimens; on the contrary, six types of diodes tested failed to withstand any of the treatments. It would thus appear that should further studies confirm the report of Phillips and Hoffman (11) of internal contamination of some sealed components, our preliminary findings indicate that most of the types in use can be safely subjected to 121 C for 16 hours, or even 140 C for 3 hours. The use of gamma ($Co^{60}$) radiation for other types, especially the manifestly heat-sensitive diodes, will be investigated.

In a strict sense, the killing of bacteria is a process whose result can be assessed only in terms of probability. Organisms generally die logarithmically, i.e., the logarithm of survivors plotted against time yields a straight line. For example, a given

heat-treatment may be said to result in 99.99 percent killing. Because of this consideration, the likelihood of impacting a living organism from a given space vehicle on a celestial body may be stated in terms of probability, just as the changes of a chain reaction were assessed prior to detonation of the first atomic bomb. It has been suggested by Davies and Communtzis (2) that the probability of contamination of Mars and Venus with a living organism be limited to $10^{-6}$, and that of the moon to $10^{-1}$. Thus, if the chances of a successful impaction of a space probe on Mars is 1 to 100, it would be necessary to treat the payload in such a way that there would be only one chance in 10,000 of a living organism being present. These same authors also suggested that the pollution level be limited to $10^{8}$ dead organisms per vehicle. All of these suggested limits appear reasonable.

During the past 100 years, the contributions of microbiology to science and the welfare of man have been many and noteworthy. As we stand on the threshold of space, it is to be hoped that the excitement of planning the more obvious and glamorous activities will not result in jeopardizing the potential contributions that microbiology can make in the cosmic age.


## Acknowledgment

It is a pleasure to acknowledge the capable assistance of Mr. Joseph T. Cordaro who accomplished the laboratory investigations.

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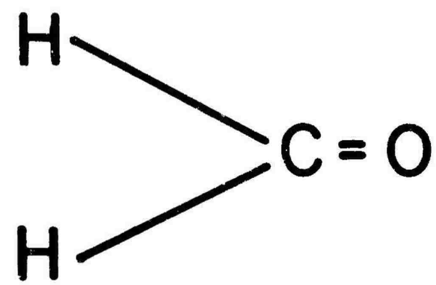
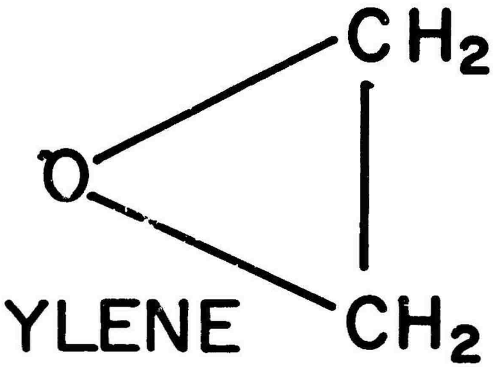
# GASEOUS DISINFECTANTS

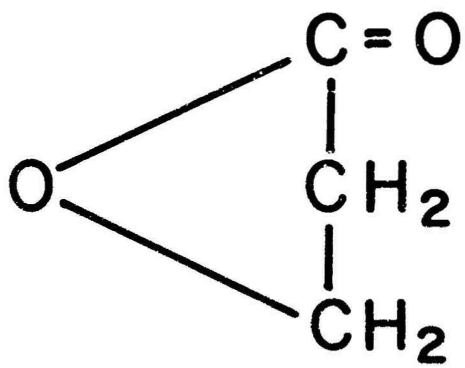
( ALKYLATING AGENTS )



FORMALDEHYDE



ETHYLENE OXIDE



$\beta$ - PROPIOLACTONE

FIGURE 1

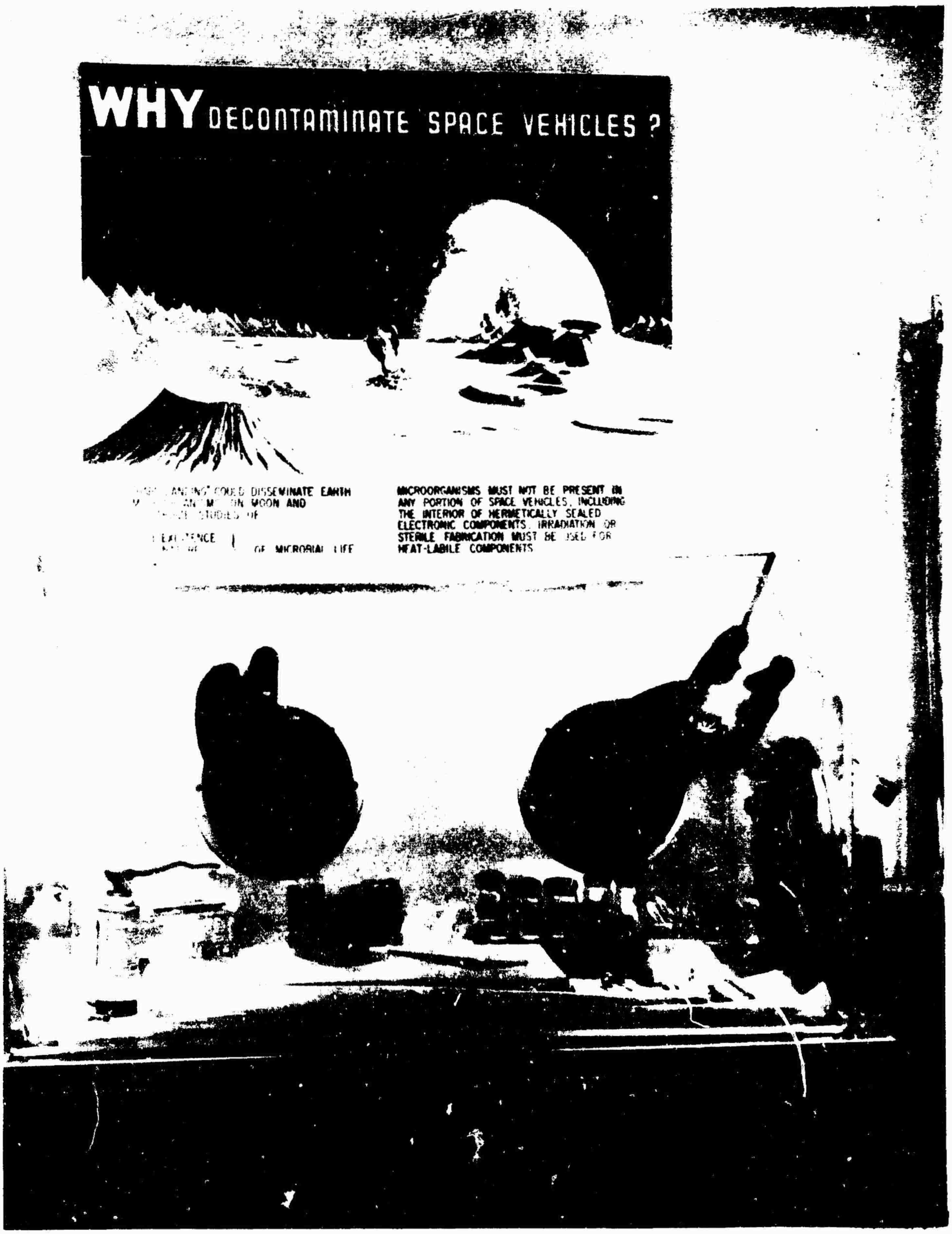



FIGURE 2

Flexible film germ-free isolator.

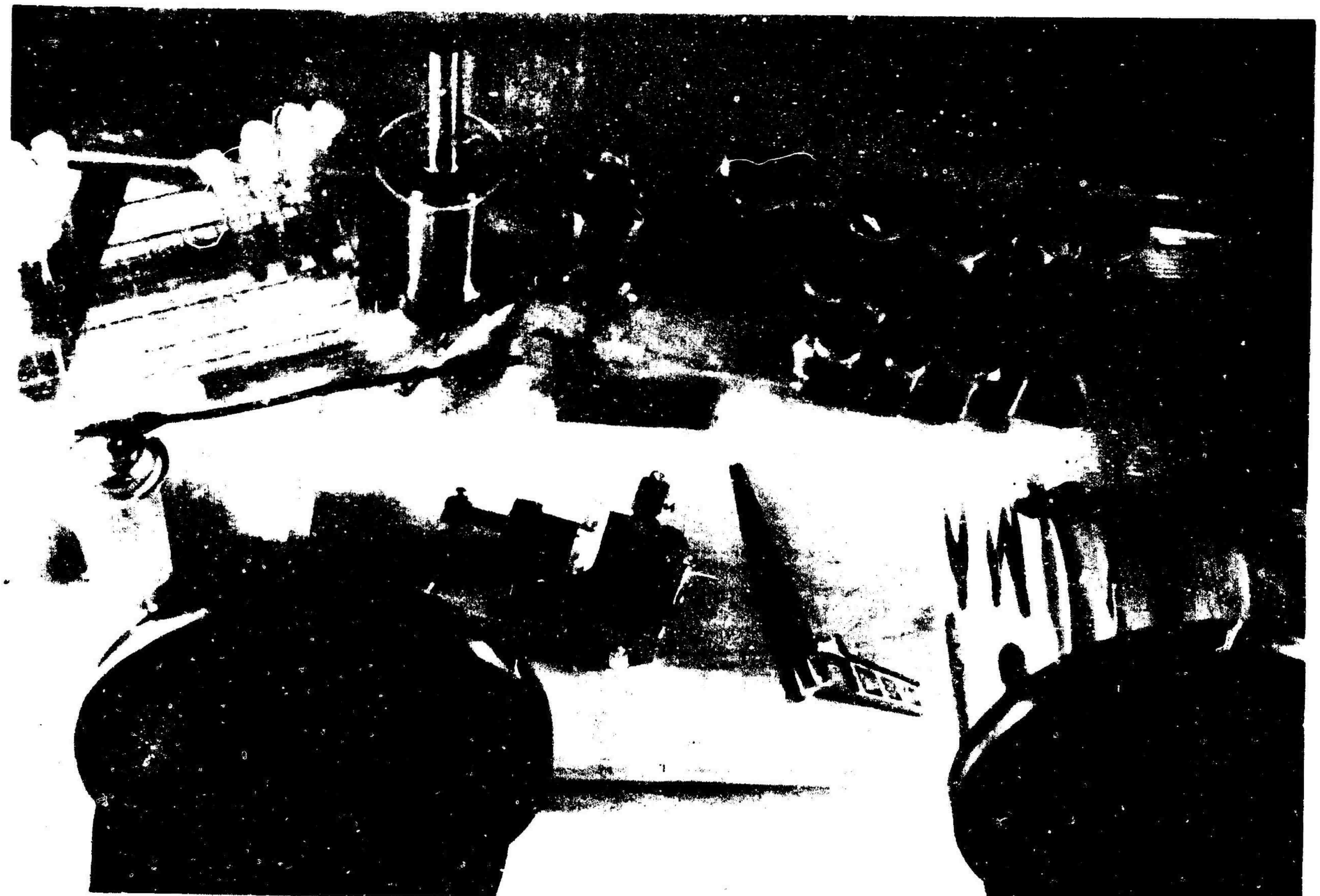


FIGURE 3

Materials used for culture of hermetically sealed electronic components.

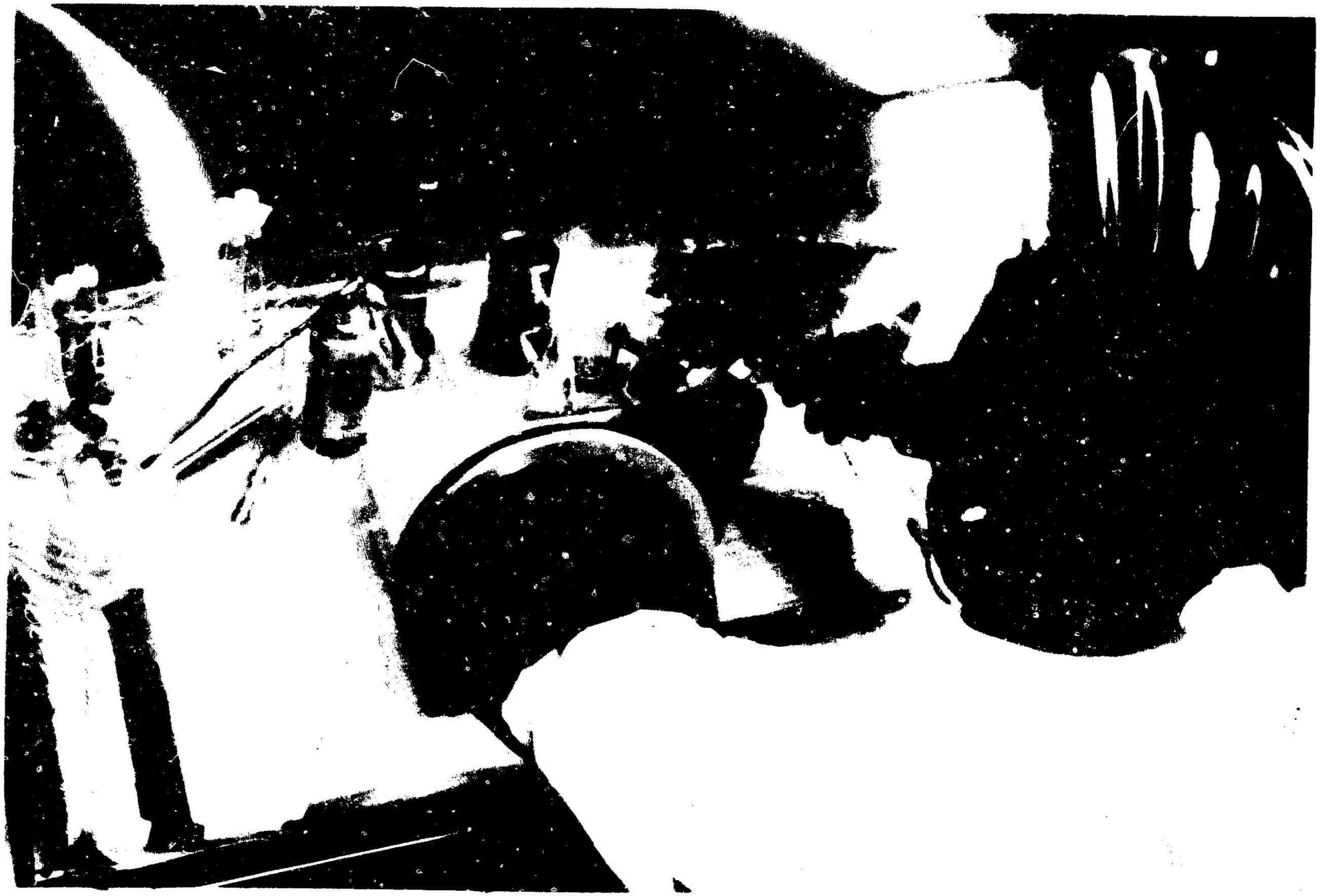


FIGURE 4

Disassembling operation for hermetically sealed electronic component.

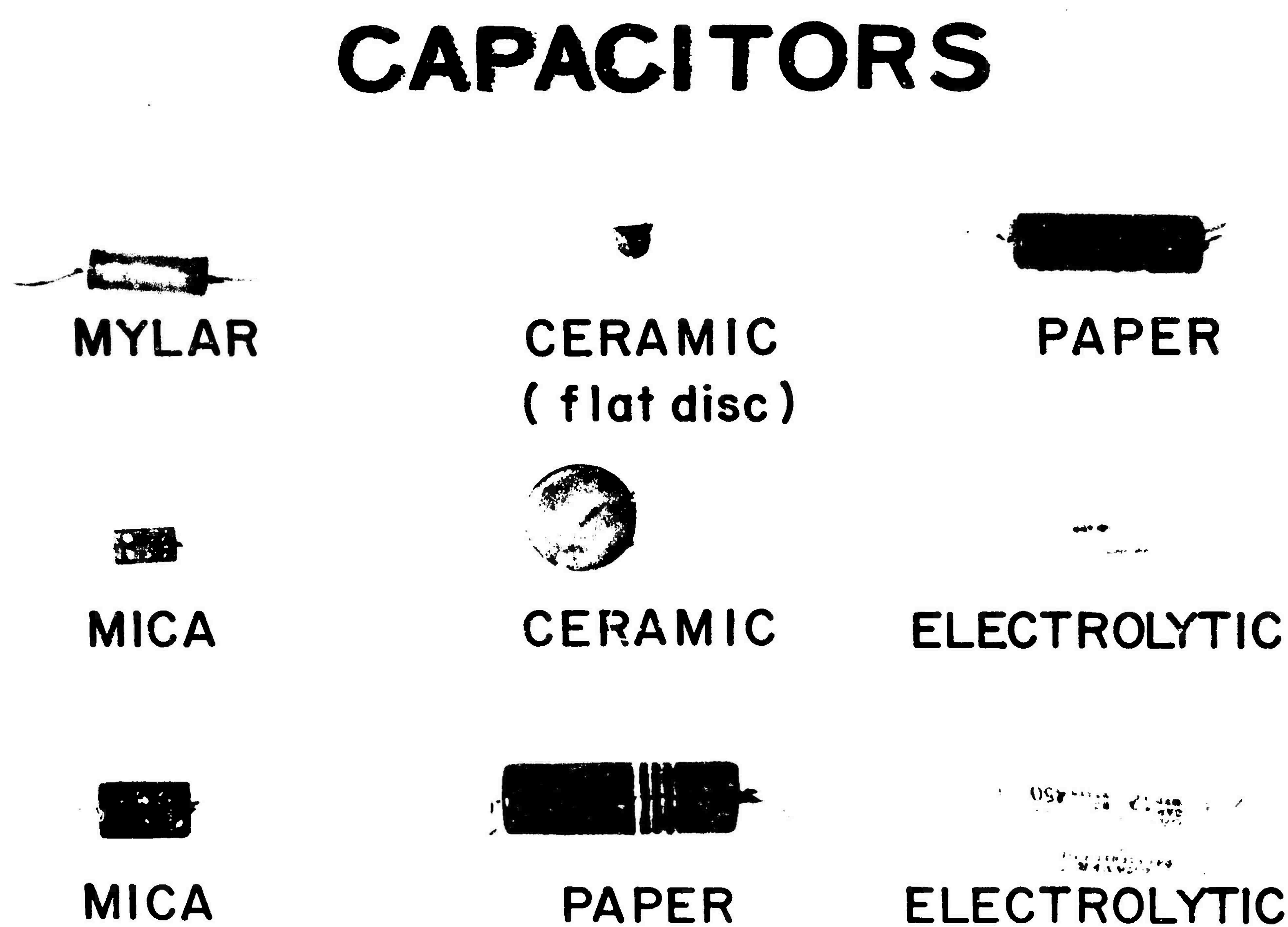
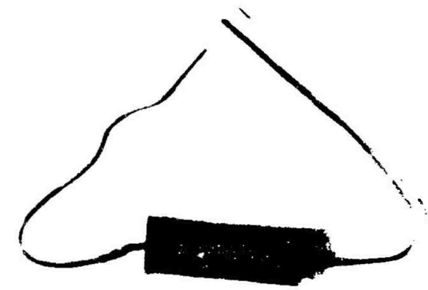

CAPACITORS
MYLAR
CERAMIC
( flat disc)
PAPER
MICA
CERAMIC
ELECTROLYTIC
MICA
PAPER
ELECTROLYTIC

FIGURE 5

# MYLAR CAPACITOR

## ASSEMBLED

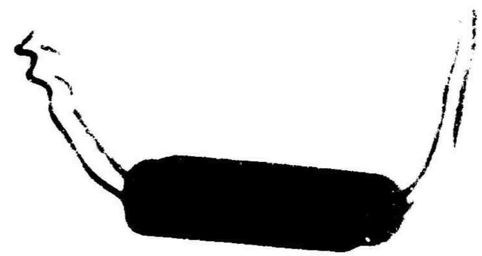


## DISASSEMBLED

FIGURE 6

# PAPER CAPACITOR

## ASSEMBLED



## DISASSEMBLED

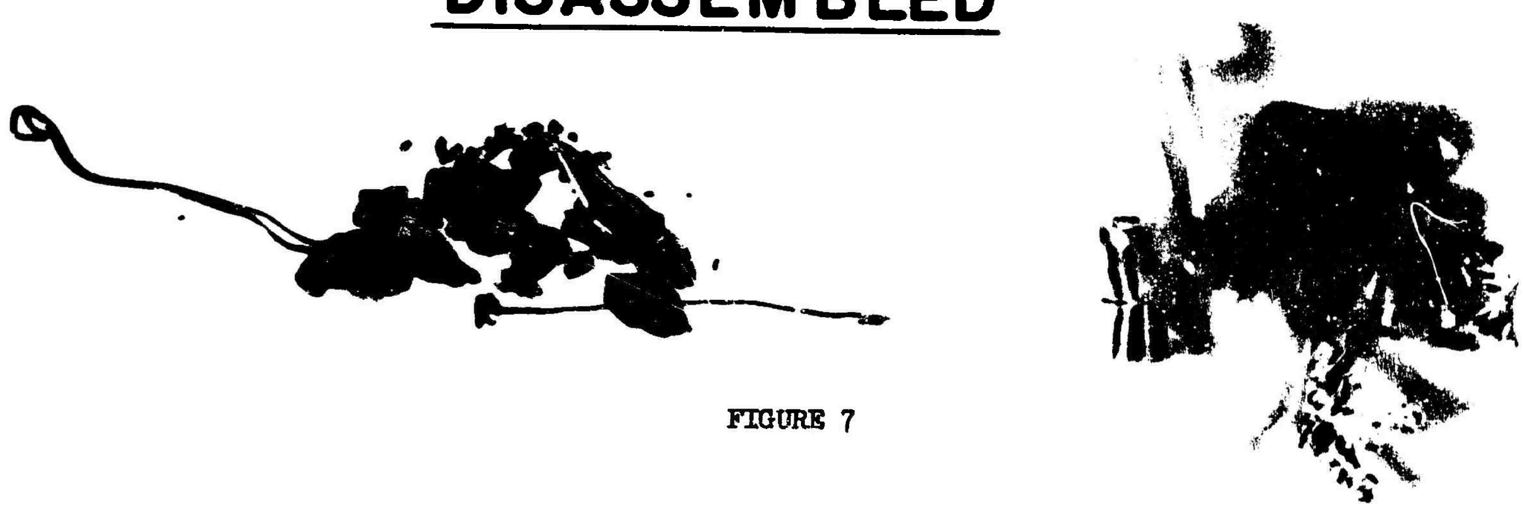


FIGURE 7

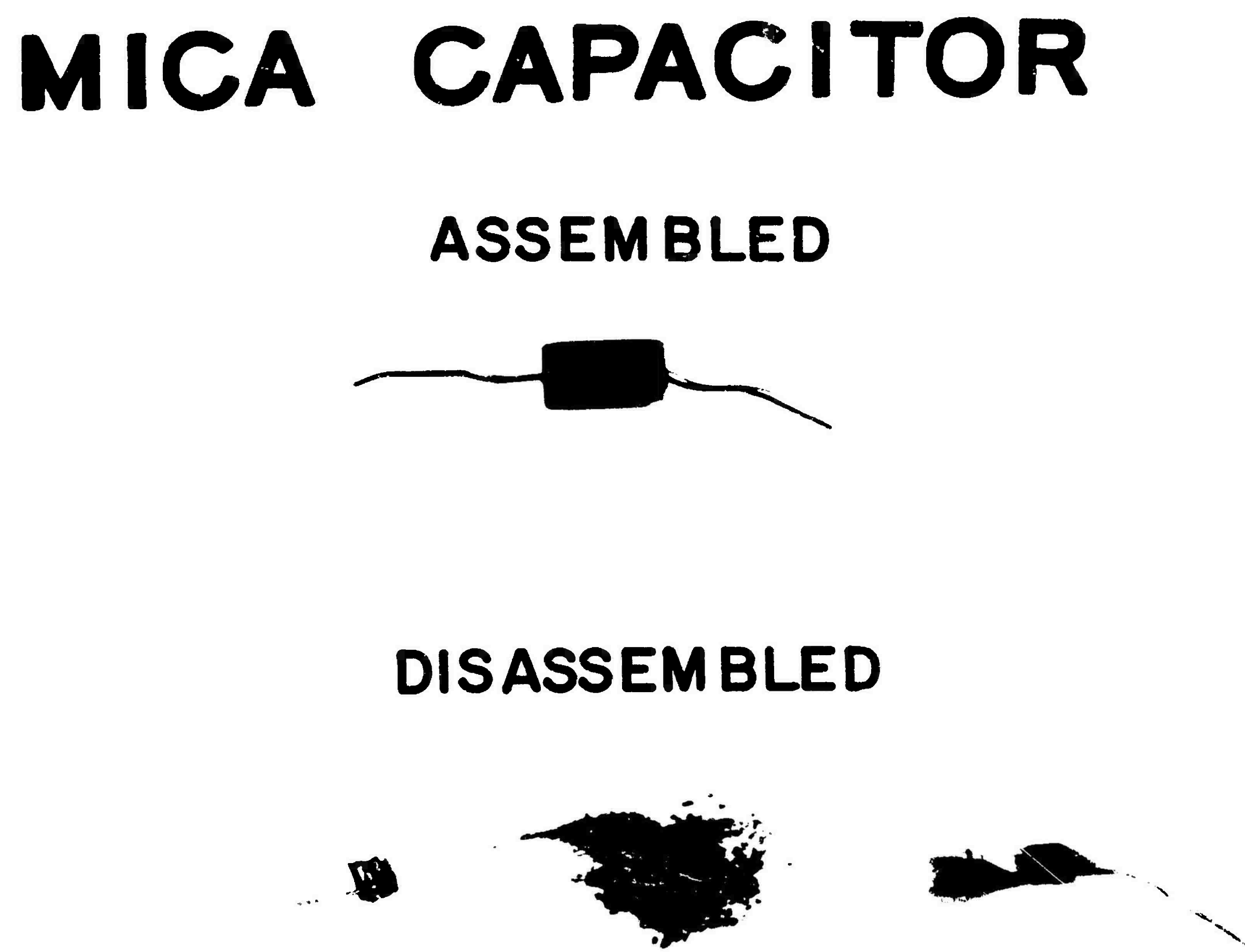



FIGURE 8

# ELECTROLYTIC CAPACITOR

## ASSEMBLED

## DISASSEMBLED

FIGURE 9

# RESISTORS

MOLDED CARBON RESISTORS

WIREWOUND POWER RESISTORS

FIXED FIXED ADJUSTABLE

FIGURE 10

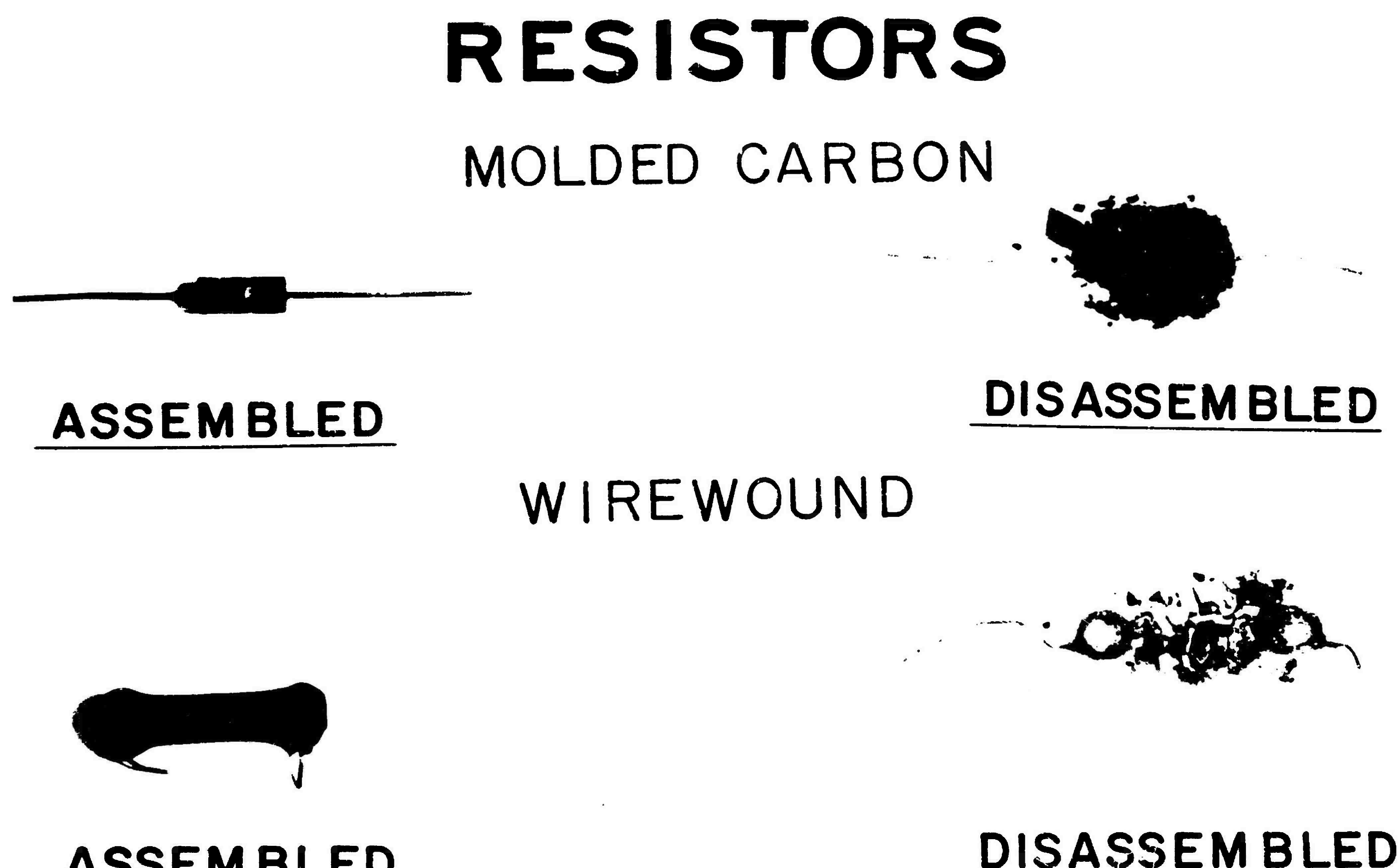

RESISTORS
MOLDED CARBON
ASSEMBLED
DISASSEMBLED
WIREWOUND
ASSEMBLED
DISASSEMBLED

FIGURE 11

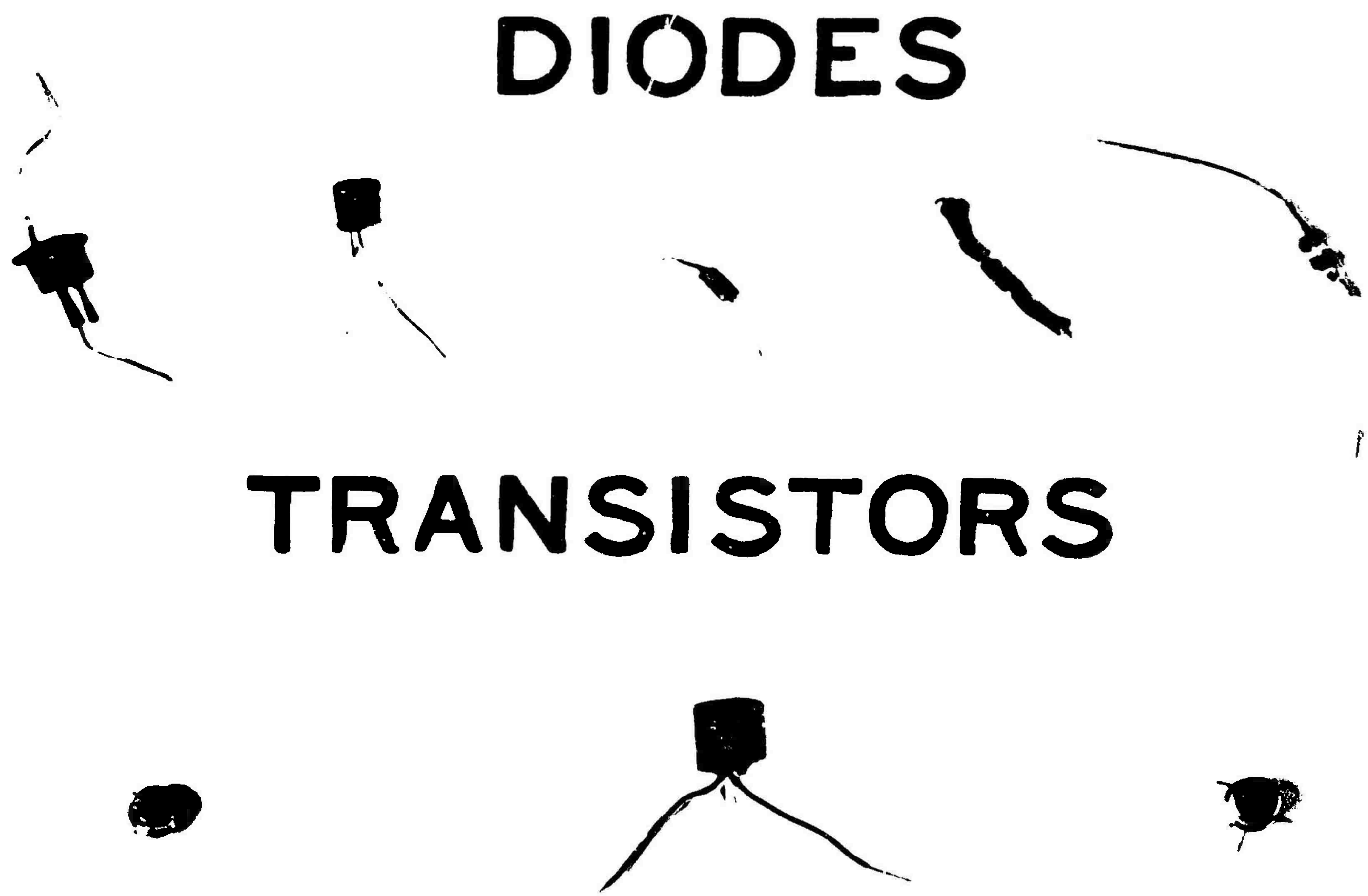



FIGURE 12

* LECTURES IN AEROSPACE MEDICINE

Future Manned Aircraft

Presented By

Mr. Scott Crossfield

Chief Test Pilot

North American Aviation, Inc.

*This article will be published at a later date.

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LECTURES IN AEROSPACE MEDICINE

MEDICAL SUPPORT AT MISSILE BASES

Presented by

Brigadier General Theodore C. Bedwell, Jr., USAF, MC

Command Surgeon

Strategic Air Command

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# MEDICAL SUPPORT AT MISSILE BASES

by

Brigadier General Theodore C. Bedwell, Jr., USAF, MC

The term "missile" as currently used in the Air Force applies to a wide variety of vehicles. The general designation includes Intercontinental Ballistic Missiles (ICBM's), Intermediate Range Ballistic Missiles (IRBM's), rocket and satellite launching boosters, air-launched missiles directed toward surface targets, which may be thought of as pilotless aircraft, and air-launched ballistic missiles.

At present, in the unclassified inventory of the United States, there are approximately 58 missiles and rockets. The agencies concerned with these include the U. S. Air Force, the Army, the Navy, the Advanced Research Projects Agency, the National Aeronautics and Space Agency, and, in some instances, combinations of these. Fourteen of these vehicles are Air Force sponsored or operated. The Strategic Air Command operational inventory, at present or planned, includes intercontinental range ballistic missiles and air-to-surface missiles.

In this discussion, consideration is limited to those occupational health problems and medical support concerns of interest with regard to the intercontinental ballistic missile. Much of the material herein is based upon data prepared at the 392d Medical Group, 1st Missile Division, Vandenberg AFB, and in the Office of the Surgeon, Headquarters SAC, for use in the forthcoming revisions to SAC publications on medical support requirements.

The nature of missile weapon systems has made the majority of commanders and their staff agencies more acutely aware of the need for consideration of health protection and human economy as they apply to the command missile mission. The number of base complexes in construction and planned which has been publicly released reveals that in the next several years the missile force will rapidly become a major component of our deterrent posture. The inventory of the intercontinental ballistic missile in SAC is increasing. The Atlas (officially designated as the SM-65) is operational with an increasing number of missiles being placed on alert. The Titan (the SM-68) in its first version is scheduled for the immediate future. The hardened, dispersed, and mobile Minuteman (SM-80) is well along in research and development.

There are 21 publicly announced bases which will serve as missile support facilities.[1]

These vary as shown in Figure 1 from the 3 x 3 type complex (three block houses and three launchers at each block house location) to the 1 x 12 configuration up to the Minuteman Farm. The Mobile Minuteman Squadrons will consist of from three to five missiles per railroad train which will be operated on a random basis over railroad trackage in the mid-western and western portions of the United States.

From the inception of the missile program, the medical service at Headquarters Strategic Air Command has been closely associated with staff agencies responsible for the development of requirements for these systems as well as those concerned with missile operations and maintenance. The general problem of health protection and health maintenance associated

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with the missile program has been given cognizance and study by physicians with special knowledge and training in aviation and occupational medicine and by industrial hygiene engineers of the medical service. Research and development agencies have been informed of command requirements for medical support, health protection, and health maintenance, as well as our concepts of operations for support.

Considerable effort has been exerted to provide advice and consultation to such agencies as the directorate of civil engineering, directorate of plans, and the directorate of materiel with regard to potential health hazards and human efficiency requirements. Appropriate medical portions have been included in the various command plans and documents associated with the missile program. The over-all medical support procedures have been developed so as to closely follow the operational and logistic plans for each system. Careful study has been made of the potential hazards involved in launch complexes and missile maintenance facilities and optimum means of minimizing them. Also considered have been the differences in operational situations as contrasted with research tests or training activities. The relative cost of an idealistic medical support program, including completely self-contained air stations with a 24-hour coverage at each launch complex, was carefully weighed against other methods of providing medical support. Manpower costs, medical training requirements, and the lack of evidence to support the requirement for such service indicates that doubtful benefits would be received from such an idealistic operation.

As a result of this evaluation, a policy consistent with economy of effort, conservation of resources, and actual requirements was developed to provide medical support as follows:

First, a preventive medical and occupational health program similar to that of large chemical industries would be applied as an extension of the existing aerospace medical program. This consists of the necessary preplacement and periodic physical examinations to be conducted in the Air Force clinic at the home (support) base and environmental health surveillance by industrial hygiene engineers and preventive medical technicians at the sites. All other medical care for missile personnel and their families is provided at the established medical facility of the support base.[2, 3]

Second, all missile personnel are given an expanded training program in self- and first-aid. In the event of a major accident, light aircraft, helicopter, or ambulances, depending upon the distance, will be utilized to transport medical teams to provide medical care or to evacuate casualties to the hospital. Medical response to missile accident situations is part of the over-all missile accident emergency and disaster control planning for the base and will be discussed briefly later.[4]

The environmental problems associated with missile operations are in reality little different from those well-defined for the Air Force and civilian industry in general. The basic principles of occupational health, with little modification, are applicable to the problem areas in the operation and maintenance of the ballistic missile force of an operational command.

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It must be emphasized that the missile environment in an operational command, such as the Strategic Air Command, is not the same nor are the problems comparable to those associated with a test and training base. As an example, present plans for operational bases except Vandenberg AFB do not envision test or training firing, either static or actual, although practice propellant loadings will occur. At operational sites, a number of problems relating to human performance and efficiency arise due to site location in remote areas, relative monotony of operations, and the fact that the force is, indeed, on continuous alert status. Each individual and his actions or reactions are critical to the operational reliability of the missile. Illnesses which would require a site crew member to seek medical attention away from his duty station could be of major importance due to the small size of the crews and the relative importance of each crew member.

Conditions which tend to degrade human performance and efficiency also become a matter of major concern. As a result of this situation, many of the traditional problems of occupational health in relation to worker fatigue become of major concern. The necessity for identifying conditions which produce a degradation of human performance and which are a result of other than direct environmental stress makes it imperative that all medical officers in Air Force clinics serving in missile organizations be aware of the fundamentals of occupational health. They must be concerned, not only with diagnosis of toxic effects, but also with over-all health maintenance.[5]

Among the less obvious environmental stresses which may be a factor in individuals seeking medical advice with vague and ill-defined symptomatology are poor nutrition, job dissatisfaction, mild or even serious personality and emotional conflicts with co-workers or supervisors, similar conditions, non-job connected, familial problems, boredom, and fatigue as a result of off-duty recreational or social excesses.[6]

The medical service program for the missile personnel in SAC, as recommended for operational units, consists of those activities and functions relating to health protection and health maintenance of the individual by clinical means and those concerned with detecting and controlling adverse environmental stresses at his place of work. These two functions are related since man and his environment are inseparable. The individual will be affected by uncontrolled environmental stresses and, in fact, the existence of these stresses may be detected early as a result of a careful history and physical examination.

Occupational health surveillance not only must insure that the individual is physically and psychologically suited for the position to which he is assigned, but also must insure that he has no predisposing conditions which might cause him to be more susceptible, than others, to impairment of his physical well-being as a result of exposures in the occupational environment. It is, therefore, necessary for the Air Force clinic personnel and those associated with the aerospace medical program to be thoroughly aware of the nature of the hazards to which the personnel of the missile bases will be exposed. The classic example in this regard is the

recommendation against assignment of personnel with chronic lung diseases--such as asthma and bronchiectasis, chronic alcoholics, those who have been previously gassed or those with diminished cardiac reserve--to areas where nitric acid and gaseous oxides of nitrogen are handled. Guidance for SAC Medical Groups has been published as SAC Pamphlet 160-5, "Guide to the Occupational Health Program."[7]

Studies made by the Aerospace Medicine Service, 392d Medical Group, have indicated that in a number of instances our over-all Air Force procedures and policies in preplacement and periodic health maintenance examinations are not adequate with regard to personnel of missile organizations. An interesting finding in this study is that, as is to be expected, there are fairly adequate medical records on rated personnel who have been assigned to missile organizations. On the other hand, among non-rated officers and enlisted personnel, there is a paucity of data with regard to information and records of physical examinations or else such records as are available are outdated. This reflection on the relatively higher degree of emphasis placed on health maintenance and surveillance of flight crews, as contrasted with other Air Force personnel, indicates a need for expanding the traditional concern with regard to the flyer to those in the missile age engaged in the wide variety of industrial operations.[8]

Among the major problem areas are those with regard to color vision, hearing, stress diseases, and physical disabilities. The studies at Vandenberg AFB have shown a significant number of individuals with known defective color vision being assigned to jobs which actually require

normal color acuity. Certain positions on launch crews involve significant exposure to hazardous noise levels. Certain others require that the individual possess an adequate hearing ability. The need for baseline and periodic audiograms is obvious. With regard to stress disease and physical disabilities, the foregoing comments regarding placing the right man at a task which he is capable of accomplishing and the variety of situations are directly applicable. One of the more significant findings in these studies has been the lack of baseline physical examinations upon which to make determination following subsequent evaluations rather than defects which have been overlooked. It is also remarkable that a need apparently exists for greater use of clinical records and the proper recording of all medical information. A change should be made a matter of record. Recording a change in physical condition when it is detected is more important than discovering it at a later date, especially if the individual has already received training on his job.

A matter of very real concern in this regard also is the fact that specific defects are not being properly recorded in the present physical profile system. As a result, a limitation in capability may not be taken into consideration in the selection of an individual for a particular career field or for a particular job assignment. Within the Strategic Air Command, it has been recommended (in SAC Pamphlet 160-5) that an additional paragraph should be added with the physical profile serial report shown in AFM 160-1 to give information in this regard so that commanders and personnel agencies will be advised.

There is a need for greater emphasis on medical selection procedures and the criteria therefor as is borne out by the fact that investigations of missile accidents and malfunctions have indicated that fatigue and physical conditions appear to be a contributing factor to a significant degree. Predisposing physical conditions may contribute markedly to these reactions. Analysis of a large number of missile failures and accidents reported by Headquarters ARDC has indicated that the vast preponderance are traceable to human failure or human error.[9] Taking into account the long hours required in certain missile operations and the fact that certain skills normally present in the Air Force must be adapted to new situations with possibly increased hazards makes this a matter of continuing study and concern.

It has been indicated in the foregoing that preplacement and periodic physical examinations are an essential part of our occupational health program. The extent of the examination and frequency of accomplishment following the initial examination depends to a large measure upon the extent of the exposure and degree of hazard involved. Evaluation of potential work situations and relative hazards by the industrial hygiene engineer is of value in this regard. Insofar as physical examinations are concerned, at the present time, there are three groups of occupations which are considered of major importance. These include personnel working with hydrocarbon fuels; those working with the hazardous propellants, such as hydrazine compounds; and those engaged in occupations similar to those fairly routine in the Air Force, i.e., involving exposure to radiation, noise, other toxic chemicals, and so on.

The recommended procedures for physical examinations for persons in hazardous occupations are contained in the Manufacturing Chemists Association's Chemical Data Sheets and various references in the professional literature. Some general information on these procedures is contained in Air Force Pamphlet 160-6-3, Health Hazards from Propellant Fuels and Oxidizers. More specific suggestions are in the previously referenced SAC Pamphlet. In general, physical examinations of hydrocarbon fuel handlers should include an X-ray of the chest, hemoglobin determination, differential, erythrocyte and leukocyte count, and complete urinalysis. Examinations for personnel handling nitric acid compounds should include X-rays of the chest, hemoglobin, complete urinalysis, erythrocyte and leukocyte determination, and determination of the history of previous exposure. An examination for hydrazine and unsymmetrical dimethyl hydrazine handlers should include an X-ray of the chest, complete blood count, including hemoglobin, cephalin flocculation, and urinalysis, including BUN. A complete physical should be given hydrocarbon fuel handlers annually. An abbreviated examination for those working with hydrazine compounds should be given at approximately monthly intervals to include hemoglobin, complete blood count, and BUN. A complete physical should be given semi-annually.[10]

In all physical examinations, great care must be given to the history and attention must be directed to some of the less obvious symptoms, particularly with regard to vertigo and other conditions which may be a problem with personnel working in confined spaces or at elevation, such as on a gantry or in a silo.

While every effort has been exerted to assure that the missile work environment is made as free of health hazards as possible, it must be recognized that continued industrial hygiene surveillance of missile activities is necessary. Many of the occupational health problems in missile organizations are similar to those at any base, hence no special discussion thereon is given here. Some comments regarding certain specialized problems are considered appropriate.[11]

At the launch emplacement or missile launching pad, one will find propellant and oxidizer storage tanks with an array of piping and valves associated with the transfer systems of liquid propellants. These are typically found with the Titan and Atlas systems and will not be located at Minuteman complexes since the Minuteman utilized solid propellants. A typical view of the high pressure gas storage cylinder and some of the piping is shown in Figure 2. The vast majority of missile launch locations currently being built and programmed for the future are the hardened variety with the missile in a coffin enclosure or silo. The problem of potential release of high pressure gases into these closed environments requires some special consideration. A wide variety of high voltage electronic equipment is also located at the launch area.

The principal propellants used in the current series of missiles are RP-1 (a hydrocarbon) and liquid oxygen. Future propellants, especially those of non-cryogenic nature which are potentially more toxic, include materials such as hydrazine, unsymmetrical dimethyl hydrazine, aniline, nitrogen tetroxide, and similar materials. Industrial experience in the

handling of these chemicals has been fairly extensive, though generally, except in the largest manufacturing plants, not in the quantities nor under the pressures involved in the missile program. Quantities of these materials will be in storage at the launch site and perhaps at the missile home base. It is essential that all personnel in the propellant storage and handling areas be indoctrinated in the nature and characteristics of the materials they use and in the safety precautions to be observed. Observance of safe handling practices will do much to eliminate the possibility of injury. It is essential that such personnel be informed regarding first-aid and emergency procedures to be followed pending the arrival of medical help. At appropriate locations, emergency showers and eye baths are provided as shown in Figure 3.

Where the work procedures so indicate, protective clothing must be available. This clothing, much of which is standardized, and available through normal Air Force channels, must be suitable to the degree of hazard involved since by its very nature it tends to restrict the activity of the individual wearing it in the performance of his duties. The duration of potential exposure and relative toxicity of the material concerned may require that the individual be completely protected from both liquid and vapor contact, as shown in Figure 4, or merely provided respiratory protection in addition to such other specialized requirements as may be indicated, as shown in Figure 5, with the individual utilizing a gas-mask type respirator, a protective hard hat, and a radiation dosimeter film badge. With regard to canister-type respirators, these should never be

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utilized when there is any possibility that an oxidizer and fuel combination may be present in the environment where the individual is to be working since a fire could result in the canister.

Propellant and oxidizer storage areas present a hazard in view of the possibility of accumulation of vapors in underground enclosures or tightly confined spaces. Even with regard to RP-1, a hydrocarbon resembling kerosene and therefore generally considered to be relatively innocuous, the possibility of serious harm exists. It must be remembered that petroleum hydrocarbons and their vapors can produce narcotic and anesthetic reactions if present in sufficient concentrations. Exposure to very high concentrations, 20,000 to 30,000 parts per million, may be fatal. The two-man system should be utilized for personnel entering underground exposures or other closely confined areas. Tests should be made prior to entry of such areas to determine the atmospheric suitability for human occupancy. A wide variety of detection devices are available and authorized to medical service engineers in the current allowance documents.

Frequent visits, by medical service preventive medical personnel, to the missile areas should be made to check on environmental conditions and to verify the calibration of those devices in the hands of operational personnel. Some of these devices are shown in Figure 6.

The majority of Atlas and Titan facilities have associated therewith an auxiliary power plant. Sound levels, well in excess of those recommended as permissible exposures in AFR 160-3, have been detected in many

of these installations. Over-all sound pressure levels of 105 to 115 db re 0.002 microbar have been measured with only 2 of 6 required generators in operation. The allowable exposure time is approximately 90 minutes per 8-hour day, taking into account the acoustic spectrum. The necessity for preplacement baseline audiograms and periodic examinations is obvious. Use of hearing defenders for personnel required to be in these power stations is mandatory. Periodic noise level determinations must also be made by medical service personnel in work and sleeping areas adjacent to these facilities since changes in operations or building configuration may alter protective characteristics.

Those missiles requiring liquid oxygen create a heavy requirement for this material. Liquid oxygen generating plants of large capacity are located at the strategic missile support bases. These plants produce liquid oxygen and liquid nitrogen as required by compressing, cooling, and distillation of the atmosphere. The diesel powered plants are accompanied by high intensity sound fields, such as are normally associated with the diesel engines. The electrically powered plants are quieter though considerable noise problems have been created by the compressor and oxygen equipment. The necessity for acoustical protection of the worker has been evaluated and here, again, hearing protection is mandatory. The problems of handling liquid oxygen are principally those for protection of personnel against freezing and avoidance of the fire hazard which results in an oxygen rich atmosphere.

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Nuclear safety and radiological health considerations as applied to the bomber force also pertain to missile organizations. The primary responsibility for the health physics program is assigned to the medical service by Air Force directives. Close working relationship must be maintained with operational, maintenance, and safety activities to assure that the mutual aims are achieved. Radioactive components are, of course, involved with certain of the re-entry vehicles as part of the warhead. In addition, other radioactive materials may be present in the form of electronic components of the re-entry vehicle. Radioactive materials may be present in missile control centers and in various ground support items. An industrial hygiene engineer must be kept apprised of the location of these items in storage and where they are maintained and worked upon. Routine monitoring of areas in accordance with existing directives and technical orders must be accomplished. One example of an unusual application of radioactive material is the static eliminator bar used in the automatic programming checkout of equipment console. This is a metallic bar coated with polunium 210 powder. This material is an alpha emitter with a half-life of 138.3 days. The emissions of alpha particles ionize the air which, in turn, causes a movement or leaking-off of static electricity from the automatic checkout equipment electronic data cards. There is no external hazard. Routine health physics, however, is necessary to preclude accidental ingestion or inhalation of the material. Swipe tests are required every 90 days to assure that the polunium is not flaking off the bar. In the event of a fire in the equipment, respiratory protective

devices should be worn by firemen and a careful alpha survey should be accomplished by the medical service following control of the conflagration.

There are a number of operations in which potential trauma may result due to explosion or fire. These include propellant loading of missiles, subsequent defueling operations, installation of pyrotechnics, and transportation of propellants. Supervision from a safety aspect of these operations is under the purview of the Director of Safety. The medical service, however, must coordinate with safety agencies to insure proper precautionary measures and in providing suitable protective devices. The importance of proper physical profiling in examination of the vehicle drivers, crane operators, and similar personnel is readily apparent.

Another area of concern insofar as non-chemical hazards are concerned, but requiring considerable attention on the part of the medical service, relates to the routine inspection and maintenance of missiles at launch sites. A vast majority of the maintenance operations at the actual launch emplacement involve inspection of components and removal or replacement of items. The more detailed maintenance operations are conducted at the missile assembly building at the support bases where the majority of missile personnel actually work. The inspection, removal, and replacement operations involve a number of procedures which may have associated therewith bending, lifting, and twisting motions, as well as presenting a requirement for good visual conditions. This is typified by the situation shown in Figure 7. Associated with these operations may be the production of muscle strain, bruises, trauma as a result of dropping objects, and eye fatigue.

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These problems are also associated with the necessary maintenance for launch control consoles and the electronic equipment associated with the launch control center, the equipment terminals, and at the launcher itself. The problems of exposure of personnel to severe weather conditions, particularly those associated with operations in areas of heavy snow and high wind are also receiving considerable attention. We are presently evaluating the suitability of currently authorized Air Force clothing and equipment in this regard.

There are a number of potential problems affecting adjacent civilian property which can result from the accidental spillage of hazardous chemicals or as a result of accidents involving missiles. With some of the newer propellants, there is a potential atmospheric pollution hazard which can extend to portions of the military area remote from the launcher or into adjacent civilian areas. The hydrocarbon fuels, as well as some of the proposed propellants of the future, also present severe stream pollution hazards. In order to assure that atmospheric pollution hazards are kept to a minimum, it is contemplated that fueling operations at operational sites will be conducted only when micro-meteorological predictions are favorable. Protective construction has been provided to trap and retain spilled wastes. To provide for the proper protection of the Government's interest and to maintain assurance that damage has not occurred, it is essential that proper environmental surveys be accomplished prior to site activation. These surveys provide suitable background information in the event of an actual spill or an accident so that results of tests

accomplished following such occurrence may be compared. Records of the background investigations must be maintained in the medical facility. Periodic evaluation should also be accomplished so that the data is maintained in a current status. Included should be accomplishment of tests at AMC Regional Environmental Health Laboratories on the chemical content of soil, water (with particular reference to nitrates), radioactivity of air, soil, and water, and observations on existing typical plants and vegetation in the area.

While the problem of accident potential is not as great in an operational complex as in test and training facilities, the fact remains that disaster situations, involving fuels, oxidizers, or nuclear materials may occur. In addition, personnel may become ill at work or may be injured as a result of normal operations. The widely dispersed locations of launch sites from the home support base vastly complicate the problem, particularly in view of the generally small number of personnel at each site.

The support base medical facility must plan for and be prepared to implement, as part of its over-all disaster control program, accident response teams in accordance with the base disaster control plan. Personnel and equipment must be on a ready status so as to be dispatched promptly to the site of an accident while simultaneously, after notification of the situation, other medical personnel at the home base medical facility organize to receive and provide emergency care and further treatment of casualties. Plans for missile fueling or other known hazardous

operations envision that medical personnel, as part of disaster control team components, will be on a standby basis during such periods. Whenever feasible, medical personnel and ambulances may be physically present at the launch site during the actual fueling or defueling operation when these are accomplished in accordance with a scheduled program. It must be remembered that the disaster control program is a closely integrated activity and involves not only the medical service, but also fire protection, security, information services, legal and civil engineering activities.

Experience in the Strategic Air Command has indicated the importance of having an experienced senior officer in charge on the scene and a well-established disaster control command post at the home base.[12] Medical officers must know the signs and symptoms of massive over-exposure to the chemicals involved in missile operations and the proper therapeutic regime to be followed for persons who may have been severely injured in a disaster situation.

The important feature of a disaster control program, insofar as missile operations is concerned, is the evaluation of the potential chemical contamination of the area or nearby civilian property which may have resulted. The supporting services of the Air Materiel Command's Environmental Health Laboratories in this regard will be essential.

Continued emphasis on diagnosis, treatment, and prevention on non-occupational disease and routine health maintenance for all personnel cannot be overlooked. Industrial experience has shown repeatedly that

even in industries, involving extremely hazardous operations, the greatest cause of lost time is attributed to non-occupational conditions.[13]

All of the usual procedures to maintain healthful conditions in housing, adequate sanitation, and food service facilities, environmental health surveillance over water, waste disposal, insect and rodent control, ventilation, illumination, and associated features of the Air Force must be continued. An active program of health education is necessary both with regard to the specific problems of missiles and general health promotion.

The medical solutions to the missile support problem in practice revolves around application of existing knowledge of the field of clinical and occupational medicine, as well as environmental health.[14]

Much of what we are learning in this application appears to be directly useful in the continued expansion of Air Force activities in the Space Age. We have learned that the vast majority of the missile age problems require only the extension of present knowledge or techniques or adaptation of existing methodology. Our success in meeting the goal of deterrence of war and advancement of the cause of peace may well depend upon our capability and imagination in providing an over-all aerospace medical program adequate to the demands of the present and the future.

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   (Figure 1 was reproduced and used by courtesy of Aviation Week Magazine.)

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TABLE I

PROTECTIVE CLOTHING AND EQUIPMENT FOR DAILY USE

Hood, protective, rocket fuel handlers, vinyl coated

Coverall, lightweight, flexible, impregnated and cured with a compound resistant to OOX, white in color

Gloves, 14", asbestos, neoprene, lastex impregnated

Boots, knee, rubber

Faceshield, plastic

Mask, oxygen, self-generating, chemical type, 45 Min

Breathing apparatus (Scott Air Pak), 30 Min

Mask, special air escape with partial or full face piece, 6.5 to 7 cubic feet per second

Hose, special hi-pressure filling

Respirator Assembly, portable demand

Gown, operating surgical, green

Cap, operating surgical, green, small

Trousers, operating surgical, green, medium

Gloves, surgeons, size 6

Lifeline (ropes, dacron/polyethylene, 125' lengths, 500 lb test min

Suspension harness (Bon's harness belt)

Belt, safety, neoprene impregnated, cotton web

Belt, safety, lineman's leather, with equipment

# TABLE II

## HAZARDS DETECTION EQUIPMENT

1. Carbon Monoxide Detector, Type B-1 (CO Test)
2. Velometer (Air Velocity Measurement)
3. Sound level meter and Analyser, over-all sound pressure level, and octave band analysis
4. Detector, Gas and Vapor - Combustible and Toxic (qualitative, and, to a degree, quantitative measurement hydrocarbons)
5. Recorder, Temperature and humidity (Thermal Environment measurement)
6. Meter, Foot Candle (Illumination)
7. UDMH Detector (Field Detection UDMH Vapor)
8. Gas Detector Set, Multiple Analysis (Qualitative detection of toxic gases)
9. Radiacmeter, alpha detector (page 13) (detection and measurement of alpha emitters)
10. Radiacmeter, Beta and Gamma AN/PDR 27 (Detect and measure beta and gamma radiations)
11. Oxygen Indicator (Quantitative Determination Oxygen Cone)
12. High Volume Air Sampler (Collect on filter paper particulate air pollutants)

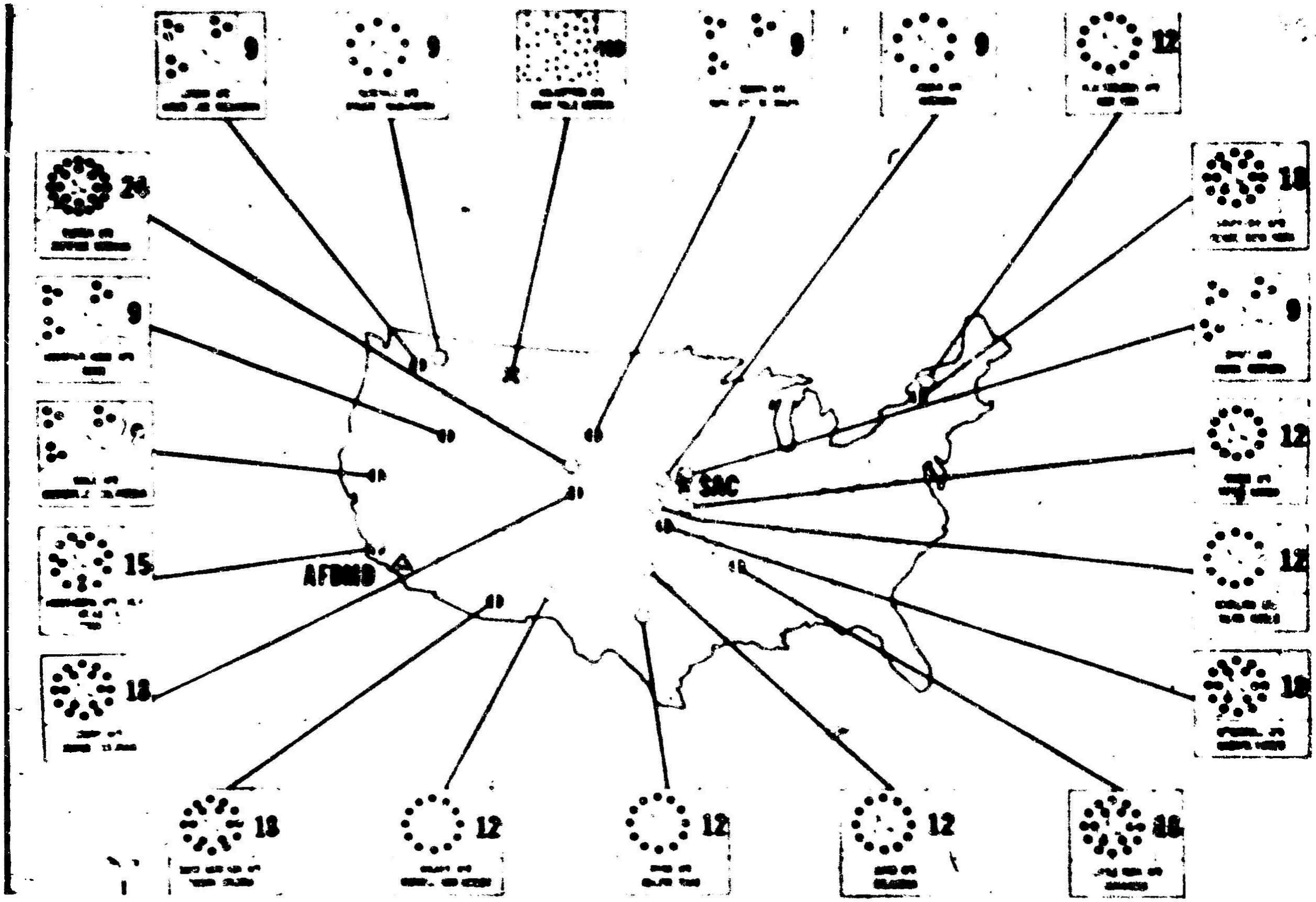


FIGURE 1

Missile Configuration

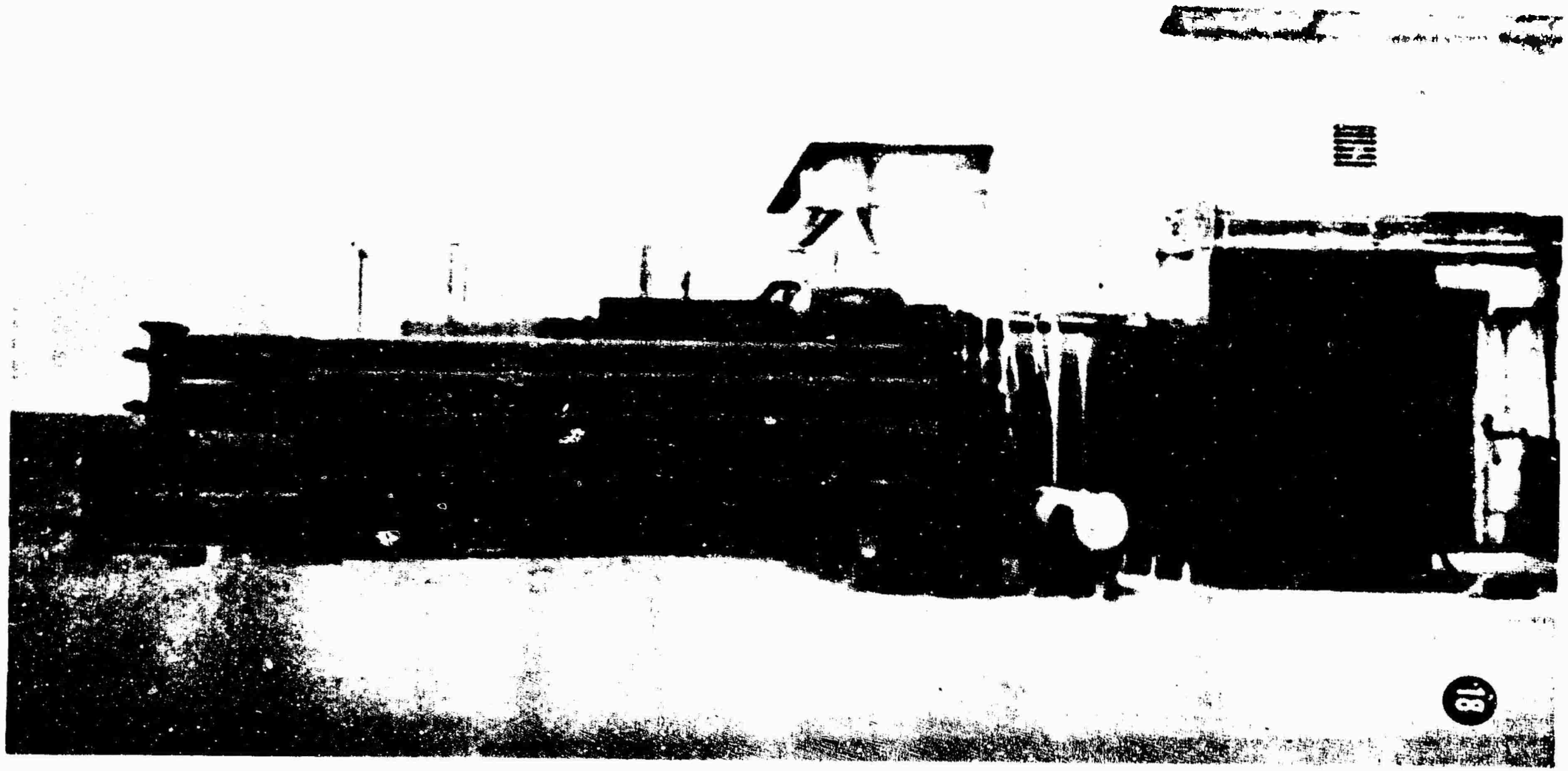

FIGURE 2

High Pressure Gas Storage Cylinder and Piping

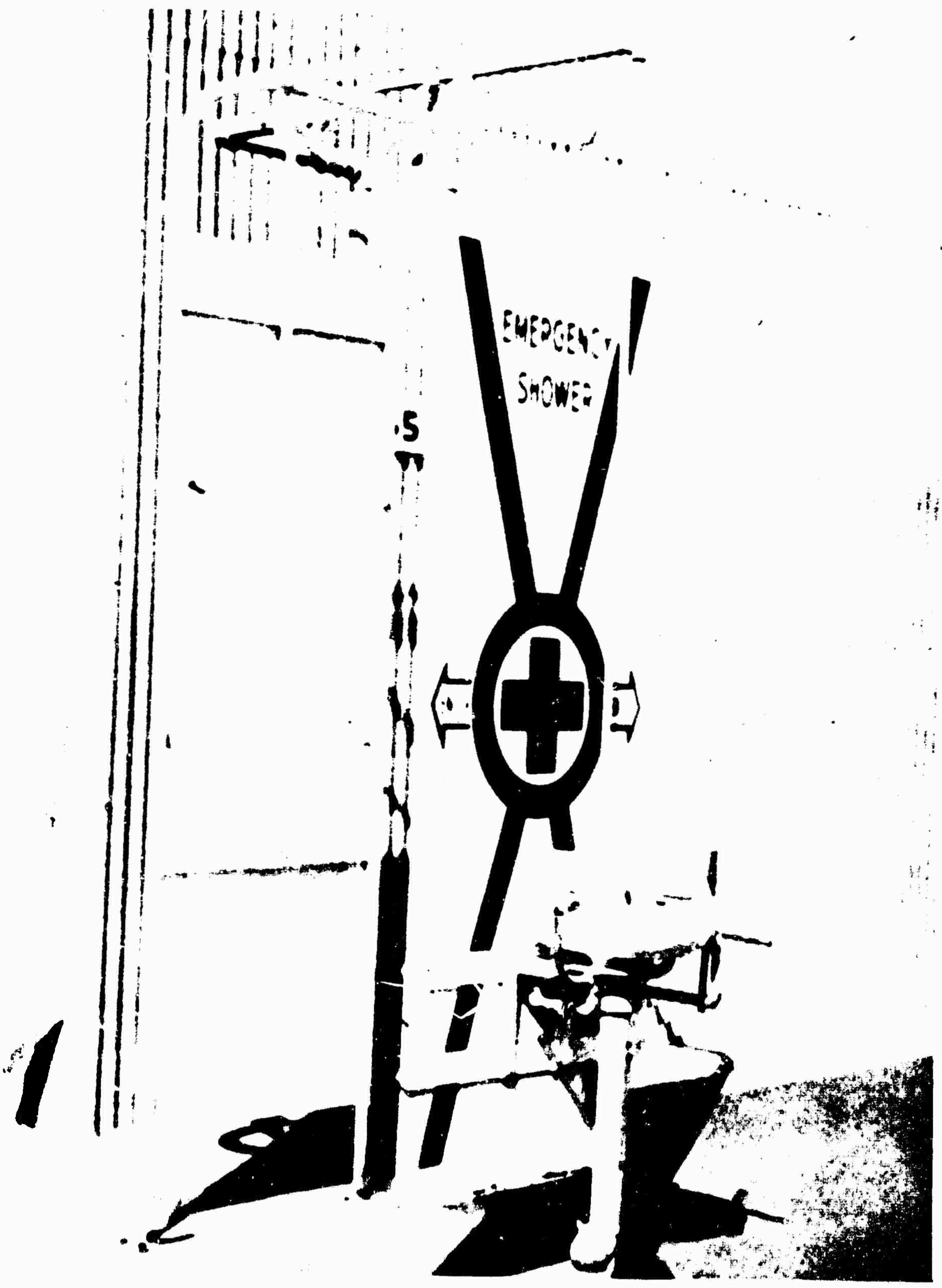


FIGURE 3

Em^rgency Showers, Eye Baths

FIGURE 4

Protective Clothing

FIGURE 5

Gas Mask and Other Protective Clothing

FIGURE 6

Devices

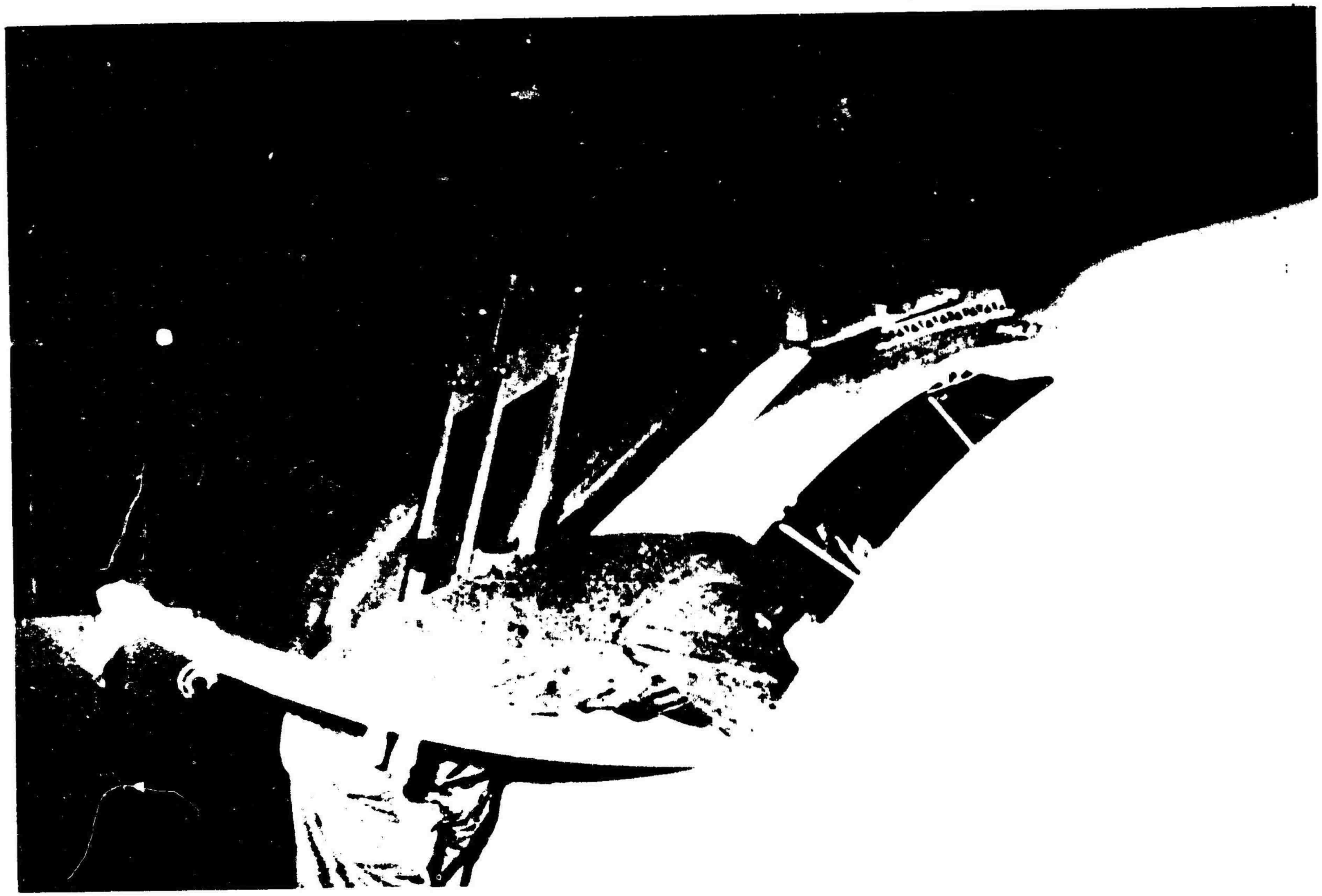

FIGURE 7

Operations-Maintenance, etc.

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LECTURES IN AEROSPACE MEDICINE

BIOLOGICAL EXPERIMENTS WITH SPACE PROBES

Presented By

Hans G. Clamann, M.D.

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School of Aviation Medicine

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# BIOLOGICAL EXPERIMENTS WITH SPACE PROBES

by

Hans G. Clamann, M.D.

The rocket-propelled spacecraft in its development toward a man-carrying vehicle differs in many respects from all other known means of transportation. No other type of man-made vehicle is able to share the realm of space with the rocket. Thus, unmanned space-probes have first to explore the unknown depths of space farther and farther from the earth to secure the future path of man. While a wealth of information on the conditions in space has been collected by such probes, the effect on man of many of those physical factors cannot be predicted immediately. Since we are not able to reproduce in our laboratories, for instarce, protons and electrons of the same energy spectrum as found in the Van Allen belts, there is only one other way: to send biological specimens into those areas of space which are of special biological interest.

In reality, certain problems of space flight occur together and are common to trips of any duration--from a few hours up to weeks, months, and years. They are directly related to the spacecraft traveling in a ballistic as well as in a Keplerian trajectory. They encompass the influence of vibration, noise, and acceleration during the phase of propulsion; weightlessness during coasting; and deceleration plus effects of heating during the phase of reentry into the earth's atmosphere.

NOTE: This manuscript reflects the views of the author and should not be considered official Air Force policy.

The influence of some of these factors, like acceleration and vibration, upon man are well-known from Aviation Medicine. In the case of weightlessness, we are confronted with a similar situation as in the case of radiation: weightlessness cannot be adequately produced on earth, which here means, over prolonged periods of time. Furthermore, the necessity arises to subject biological specimens to real space flight radiations.

All these problems just mentioned have been pointed out already by many others interested in biological space research. But there are, at present, only a few who were so fortunate as to participate repeatedly in various space shots and to accumulate practical experience. Such experience may lead to a somewhat different aspect of biological experimentation in space.

Most biologists not familiar with missile launching may underrate the complexity of such a procedure. This means, for the present "first generation" of missiles available for an instrumented "payload," that many restrictions exist for any apparatus not directly or indirectly connected with the function of the propulsive part. Such restrictions concern weight, volume, electrical power consumption, number of telemetering channels, etc. Furthermore, any payload has to be mounted in the nose cone one or more days before the actual launching. In case of difficulties during this preparatory phase or the actual "count-down," additional delaying may occur without access or a possibility of checking the functions of an experimental arrangement. This means, except for satellites, the actual "flight time" is a small fraction of the total time during which a biological space probe has to be operational.

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While this situation may improve with the technical development of the missile as a carrier, the rigid requirements for any "life-cell" will remain: to be completely self-sustaining, to withstand high accelerations and deceleration forces, vibration and temperature changes, and maybe immersion in sea water. In other words, such conditions have to be tolerated by any "life-cell," whether they are part of an experiment or not. The "life-cell" has to be developed into a "bio-pak," a self-sustaining and self-protecting unit.

The "profile" of a missile shot depends on its original schedule and may differ greatly from one firing to another. We have seen that adaptation of a planned biological experiment to an available missile shot is a paramount condition. Since even the launching of a smaller missile is a costly affair, no such opportunity should be missed when offered. But we need more definite criteria as to what specimens a biological space probe should carry and what type of missile shot is feasible.

As has been demonstrated, both questions are linked insofar as the space available in a nose cone and the planned mission of a missile constitute a frame for planning until such time as a missile will be available exclusively for biological purposes.

As to the selection of biological specimens, the existing situation may be illustrated by Figure 1. This diagram shows a variety of potential biological specimens arranged in two main groups: complete and fragmented organisms. Both are spread out along the abscissa according to the decreasing complexity of their organization. The left ordinate

points to the increasing complexity of the environmental conditions, while the right ordinate indicates the increasing necessity for protective measures. Man, at the upper left corner, is chosen as reference point for the highest complexity in every sense.

Returning to the statement made at the beginning, we need most urgently information on the effects of prolonged exposure to radiation as found in the Van Allen belt, and occurring during solar flares, and also of prolonged weightlessness, both of which cannot be duplicated on earth. Both conditions can only be produced by a satellite cruising at least one day at the required altitude. Not only because of the small space available, but also because of the simplicity of systems consisting of cellular magnitude, the choice will be on the lower right corner of Figure 1, i.e., algae, fungi, tissue cultures, etc. Besides the fact that rapidly growing systems may show radiation effects more easily, effects on algae and fungi as prospective partners in future biological regenerative systems are of immediate interest. Details on experiments of this type will be reported by other speakers.

Low organized or fragmented biological specimens are useful as basic units not affected by the interference from complex control mechanisms, such as constituted by a circulatory or nervous system. But the results obtained on tissues may not always be the same as those gained on the whole body. We need to know the influence, for instance, of weightlessness upon more complex complete organisms. The ultimate goal seems, then, the subhuman primate, which resembles man so closely anatomically and physiologically, and can perform psychomotor tests. Would this

mean that tests conducted on simpler and/or smaller vertebrates are useless?

The fact that the Russian space biologists primarily use dogs may be mentioned here. There is no doubt that smaller or sturdier mammals need less and simpler support. Of course, the results obtained on such animals cannot be extrapolated quantitatively for humans. But there is still the fact that biological systems which serve mainly one purpose in the living body show surprisingly constant characteristics. Taking, as an example, the circulatory system: in mammals of approximately the same physical activity, we may assume that the weight of the heart muscle serving as a measure of its energy should stay in fairly constant relationship to a unit of weight of body tissue it has to perfuse. Plotting the weight of the heart versus an arbitrary, but constant, amount of body weight (100 grams) in Table 1, we find, indeed, even for very different species an amazingly constant ratio. For domestic specimens, including man, this ratio varies not more than $0.42 \pm .05$, while the total body weights differ as much as 1:7,500. For wild, very active vertebrates (or capable of sudden activity), the ratio is even more constant: $1.04 \pm 0.04$, the total body weight as different as 1:1,200. The hummingbird, with its extreme muscular activity, is listed only for comparison: its heart/body weight ratio equals 2.37, more than twice as high.

Other physiological properties, expressed in relative terms, vary inversely with body weight. Plotting the heat production at rest per unit of body weight and time versus the ratio of body surface over

unit of body weight, an approximately linear relationship results (Fig. 2). Again, this relationship holds true for very different species over such a tremendous range in body weight reaching from the guinea pig (800 grams) to the elephant (3,670 kilograms), a ratio of approximately 1:4,600.

Both these examples are not meant to demonstrate biological laws, but simply the possibility of selecting smaller vertebrates as specimen for the investigation of special problems. A comparative physiological study of certain organ systems or functions as the two just listed may assist to intra- or extrapolate results in a more meaningful way.

The mouse, for instance, is a very useful animal if only a comparatively small bio-pak is indicated. The metabolism of mice is well-known; mice have been used extensively for various kinds of radiation studies.(1) Black-haired mice (C-57 strain) are especially suited to study the effect of heavy primary cosmic radiation which produces graying of hair.(2) Furthermore, C-57 mice show generally little susceptibility to sound, while other strains may suffer convulsions (audiogenic seizures),(3) and even, according to experience, die from very loud noises.

## PROGRAM "PIGGY-BACK"

About a year ago, the Ballistic Missile Division of the Air Force asked the School of Aviation Medicine (SAM) whether or not a small lifecell (bio-pak) could be made ready within a few months to be included in a ballistic missile program dubbed "Piggy-Back." This name meant

simply that a number of single "black boxes" each prepared for an experiment could be installed as ballast in the nose cone of an Atlas missile during its ballistic flight.

Strictly on a "non-interference" basis with reference to all and any instrumentation, the SAM life-cell would be the only biological experiment on board. The total bio-pak would be restricted to a maximal space of 14 x 6 x 6 inches, and a maximal weight of approximately 16 pounds. One continuous and possibly three commutated channels would be available for telemetering purposes.

Due to considerable practical experience gained in previously conducted research,[4] the challenge was accepted. Compared to an original experimental model, the new design carried, besides the various sensors, also the oxygen supply (bail-out cylinder), all necessary electronic equipment and the power supply (mercury batteries) inside of the bio-pak. Thus, the bio-pak would not release any oxygen into the nose cone in case of malfunction of the oxygen regulator system and was completely independent of the nose cone's power supply. The final design, separated in outer hull and inner structure, is shown in Figure 3.

The outer hull, (H), marked by three red rings, was machined from a solid piece of aluminum alloy into a "can" open only on one side. This "can" is to receive the bio-pak proper, (L), the one square front end, (E), of which carries the whole structure and, by means of a circular groove and an O-ring, constitutes the final seal between the outer hull and the inner structure.

Metabolic studies on mice revealed that, with the restriction in weight, volume, and with a desired life-time of the total bio-pak of four to five days, only three mice could be accommodated. Each mouse occupies one wedge-shaped sector of the cylindrical cage, (C), made from mesh wire. Around this cage, six troughs in the shape of half cylinders, two for each mouse, carry a gelatinous food. The gelatinous state serves a triple purpose: supplying the necessary water, leaving as little as possible waste, and not being thrown around at high g-forces.

The square pieces next to the cage are the batteries, (B), put together into a suitable shape from commercially available mercury cells. Not visible below the batteries are the amplifiers and subcarrier oscillator for the bioelectric signals, and temperature- and oxygen partial pressure-sensor. The connective cable, (S), transferring these signals to the main telemetering system, can be seen wound into a coil next to the front end.

The high pressure oxygen cylinder, (O), is directly connected to a two-stage reduction valve, (V), serving as oxygen supply regulator. Since the life-cell atmosphere consists of pure oxygen at one-half atmospheric pressure, the only factor decreasing this pressure is the consumption of oxygen by the three mice at a rate of approximately two liters per mouse per day, provided there is no leakage from or to the outside, depending on the pressure differential. Pressure changes due to changes in temperature are eliminated by a temperature compensator.(T)

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The only remaining conditions for constancy of the life-cell pressure are elimination of the exhaled carbon dioxide ($CO_2$) and water vapor. ($H_2O$) From the many existing absorbents, anhydrous lithium hydroxide (LiOH) was chosen after extensive tests of its absorptive characteristics under the existing conditions. In these tests, a gas stream was driven at a constant flow rate through a tube filled with a constant amount of LiOH. This gas was a mixture of pure oxygen with wet $CO_2$ in one and dry $CO_2$ in two other experiments (see Fig. 4). It became evident that the presence of water vapor flattens the exhaustion curve for $CO_2$ in the sense that increasing water vapor tension leads to an earlier but slower decreasing exhaustion of the $CO_2$ absorption capacity. A totally different result is obtained when anhydrous LiOH is first in contact with water vapor only. Within a few days, all LiOH is converted into LiOH-monohydrate. This compound has only about 5 percent of the $CO_2$-absorptive capacity of anhydrous LiOH and exhibits an almost vertical exhaustion curve. Based upon these findings, it was determined that anhydrous LiOH could absorb $CO_2$ and $H_2O$ simultaneously if the total absorption time would not considerably exceed four to five days. The lithium hydroxide was enclosed in a quilted and folded bag made of a double layer of nylon material. Thus, even at violent vibrations, dusting of LiOH was practically eliminated. This bag was wrapped around the cage and could also absorb the urine. The large area, together with the activity of the mice, made a ventilating fan unnecessary.

As mentioned before, under the given conditions and a required life-span of four days, plus an adequate safety margin, just three mice could be accommodated. Two females and one male C-57 black mice were selected. One female mouse was equipped with a saddle-shaped plate fixed on her back. This plate carried four transistors, two acting as amplifiers and two as radio-frequency oscillator. By means of embedded electrodes, bioelectric currents from the heart (ECG), the respiratory muscles, and, at increased general muscular activity, from other skeleton-muscles were picked up and emitted, by means of a small wire loop, as a modulated radio-frequency signal. Details of this "mouse-mitter," developed by the electronic section of the School of Aviation Medicine, will be described elsewhere. It may suffice to say that this unit worked well for at least four days when powered by a single small mercury cell. The transfer of this modulated signal has been referred to before.

Discussing the question, "What physiological signals from an animal would be the most informative ones," a reasonable answer can only be given for a well-known situation and mission. In general, it should be emphasized that the recording of environmental data such as oxygen partial pressure, temperature, magnitude and direction of acceleration very often permit a conclusion upon the possible state of a biological specimen without having any physiological data, but rarely vice-versa. Thus, recording of environmental data seems paramount. Another important point is to keep complete biological organisms in as good as possible state of health within the life-cell. This means careful control

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of all environmental conditions, designing of proper restraining methods for larger animals as protection against "g" forces, and provision of food and water for longer lasting space trips. Some measurements, for instance, the measurement of blood pressure with a cannula inserted in an artery, are, under the violent vibrations and "g" forces in certain phases of any space journey, a serious hazard compared with the same measurement in a quiet laboratory.

Telemetered environmental data in the experiment described here were temperature and oxygen partial pressure. Since the life-cell atmosphere consisted of pure oxygen (at half an atmosphere), measurement of oxygen partial pressure was identical with measurement of the total pressure. After some experience with the characteristics of the telemetry system of the nose cone, it was found very practical to also record the voltage of the bio-pak batteries. This made it possible, when observing fluctuations in the recorded curves, to distinguish between disturbances caused by either the telemetry systems of the nose cone or by the amplifier-subcarrier system of the bio-pak.

As already mentioned, only one mouse was equipped with a system providing physiological data because there was only one continuous channel for telemetry available. But this was not the only reason for restricting data telemetering to one mouse. In case of unexpected severe effects of "g" forces, the mouse equipped with a pack-load of approximately one-fourth of its body weight would more likely have been killed than the others. Recovery of live mice after recovery of the nose cone was regarded as the main objective.

Next to observing pulse rate, respiration, and muscular movements, a record of any kind of radiation dose within the life-cell was of primary interest. Small chemical and simple physical dosimeters (fluorescent glass rods) provided by the Radiobiology Branch covered a range from a fraction of 1r to several thousand r's.

SPECIAL OBSERVATIONS ON VIBRATION

The preliminary testing of the bio-pak included the effects of vibration. For this purpose, only a common shaker was available with a wide variability of its amplitude, (A), but a small variability of its frequency (f). Since the "g" forces caused by vibration are proportional to $f^2A$, pairs of f and A values could be found producing the same "g" force (Fig. 5). This led to the hypothesis that stress caused by such acceleration during a vibration would be proportional to such "g" forces. A curve for a constant "g" as a function of f and A is shown in Figure 6. Screening the literature, it was found that, indeed, both a curve for human vibration tolerance (Fig. 7), as well as a curve for its threshold of perception (Fig. 8) confirms this hypothesis for a wide range of f and A. (Figure 7 is adapted from Lawton and others,[5] who cite Goldman as author. But the chapter written by Goldman does not contain this figure. Figure 8, also adapted from Goldman, is cited from Békésy.) The small range between the "g" forces for tolerance (.26) and threshold of perception (.002 - .0036 "g") is noteworthy. A ratio of approximately one to one hundred is amazingly small for biological receptors, while such sensors as the eye and the ear cover an energy range of one to one hundred thousand and more. This may indicate the primitivity of such

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stress sensors developed only as warning devices. Non-uniformity in energy absorption by varying mechanical impedance, resonance, etc., is well-known and it seems surprising that such a simple relationship between a stimulus ("g" forces) and its effect exist. These findings are described here only as an example that such results and others can be found as a by-product of studies on biological space probes.

As a last example of preliminary results of the three-mice experiment, Figure 9 is presented. This figure shows the pulse rate of one mouse during the total flight. As a certain surprise, the pulse rate is influenced much more by vibration and noise than by even the high "g" force at reentry. The pulse rate climbs directly after ignition of the rocket and decreases even before burn-out. At reentry, the pulse rate climbs to a peak long before the "g" force reaches its maximum. During weightlessness, the pulse rate remains fairly constant and resembles the pulse rate found during sleep.


SUMMARY

An attempt has been made to define more closely the criteria for selecting feasible bio-specimens and biological methods for space probes. One example of a biological space probe is described. At present, because of lack of practical field experience, there is too much theorizing. Lack of communication between the right people contributes to this situation. Unfortunately, even professional people seem to prefer to listen to fantastic statements rather than to the simple truth. Terms like: "unqualified success," "milestone," "break-through," should be used more

cautiously. Educational efforts should strive more toward a depth than toward occupying additional areas.

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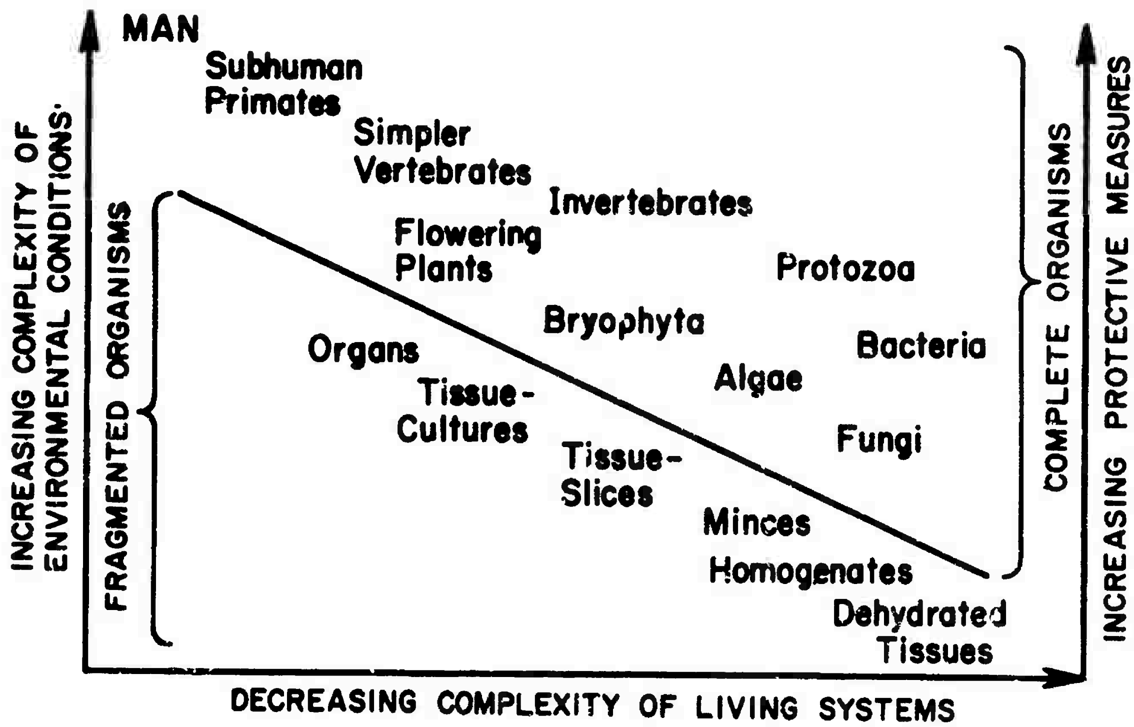


FIGURE 1

Classification of various live specimens according to their feasibility for biological space probes

# V E R T E B R A T E S

## DOMESTIC

| species | body weight, kg | heart g/100 g |
|---|---|---|
| *Hamster, golden* | 0.12 | 0.47 |
| *Cat* | 3.3 | 0.45 |
| *Man, white* | 67. | 0.47 |
| *Cattle, Holstein* | 900. | 0.37 |

## WILD, VERY ACTIVE

| | | |
|---|---|---|
| *(Hummingbird* | 0.005 | 2.37) |
| *Shrew* | 0.02 | 1.02 |
| *Hare, African* | 2.9 | 1.02 |
| *Wolf* | 22. | 1.08 |
| *Gazelle* | 24. | 1.00 |

TABLE I

Ratio of the weight of the heart in grams per 100 gram of body weight as indicator for comparable physical activity

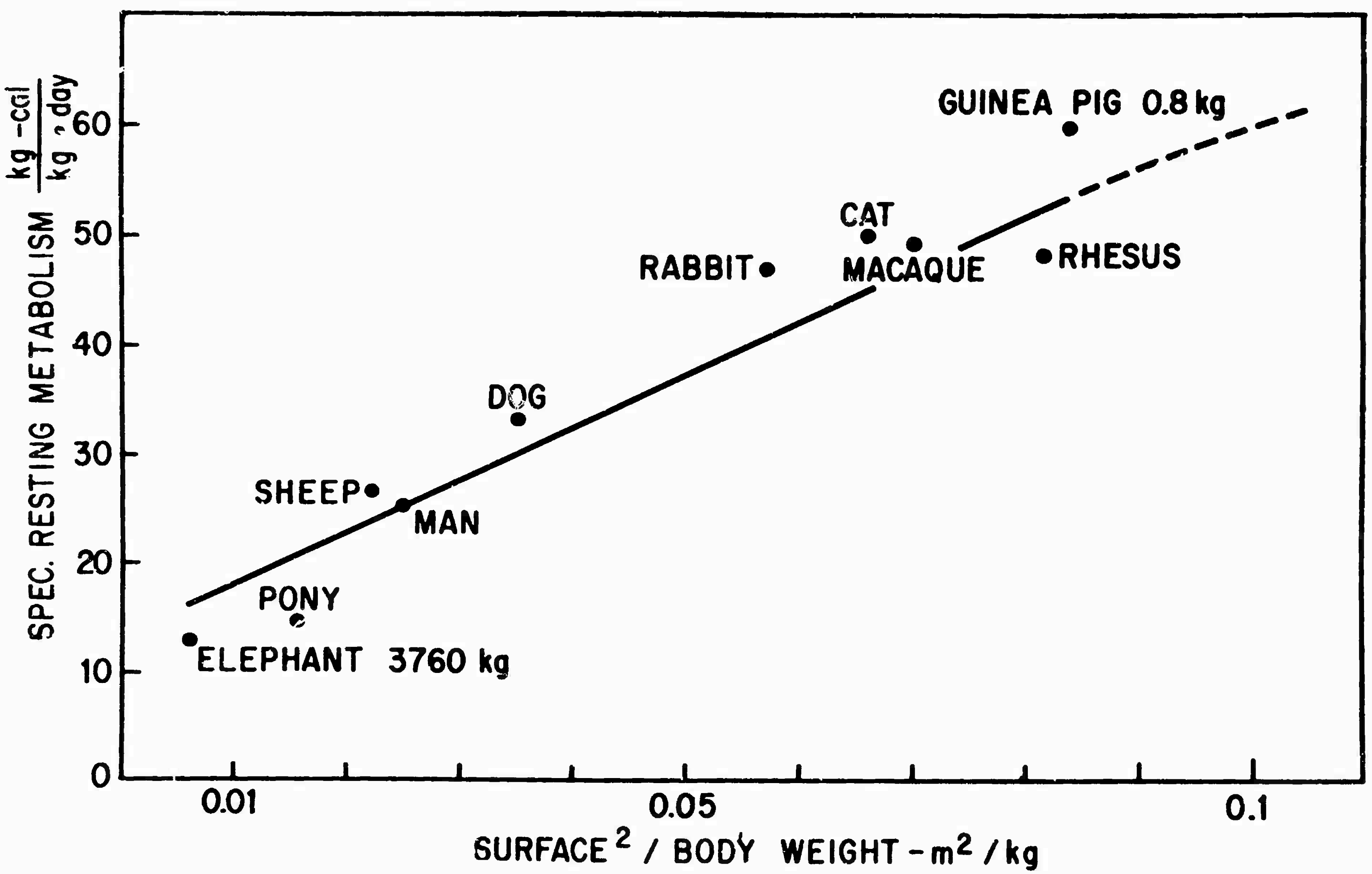


FIGURE 2

The ratio surface$^2$/body weight plotted for specific metabolism as indicator of metabolic intensity inversely proportional to total body weight

FIGURE 3

Bio-pak for the mice as used in a ballistic shot of an Atlas missile on 13 October 1960

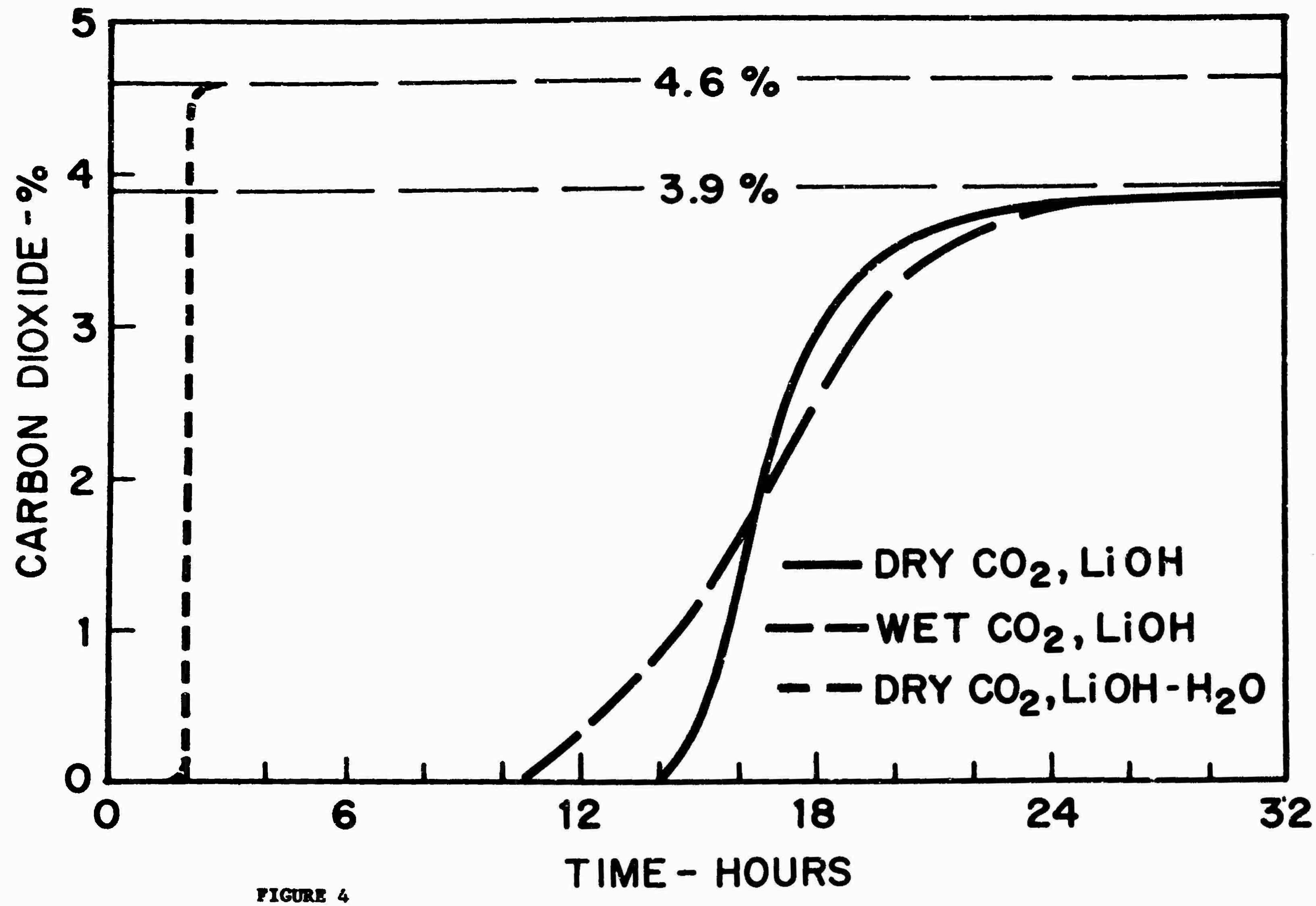


**FIGURE 4**

**Exhaustion curves of lithium hydroxide, anhydrous and monohydrate, absorbing carbon dioxide from dry and wet gas mixtures**

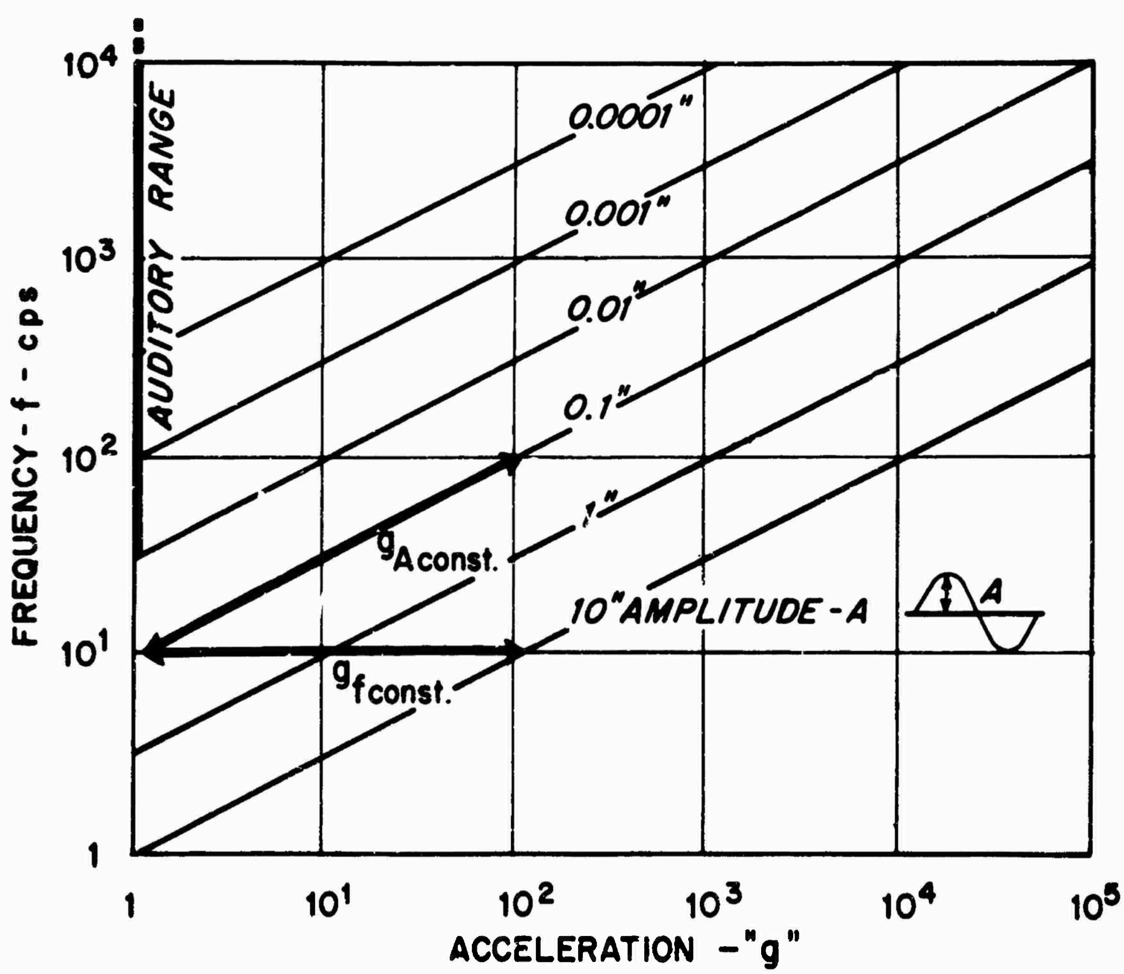


FIGURE 5

Frequency plotted versus acceleration, for various amplitude of a simple harmonic motion

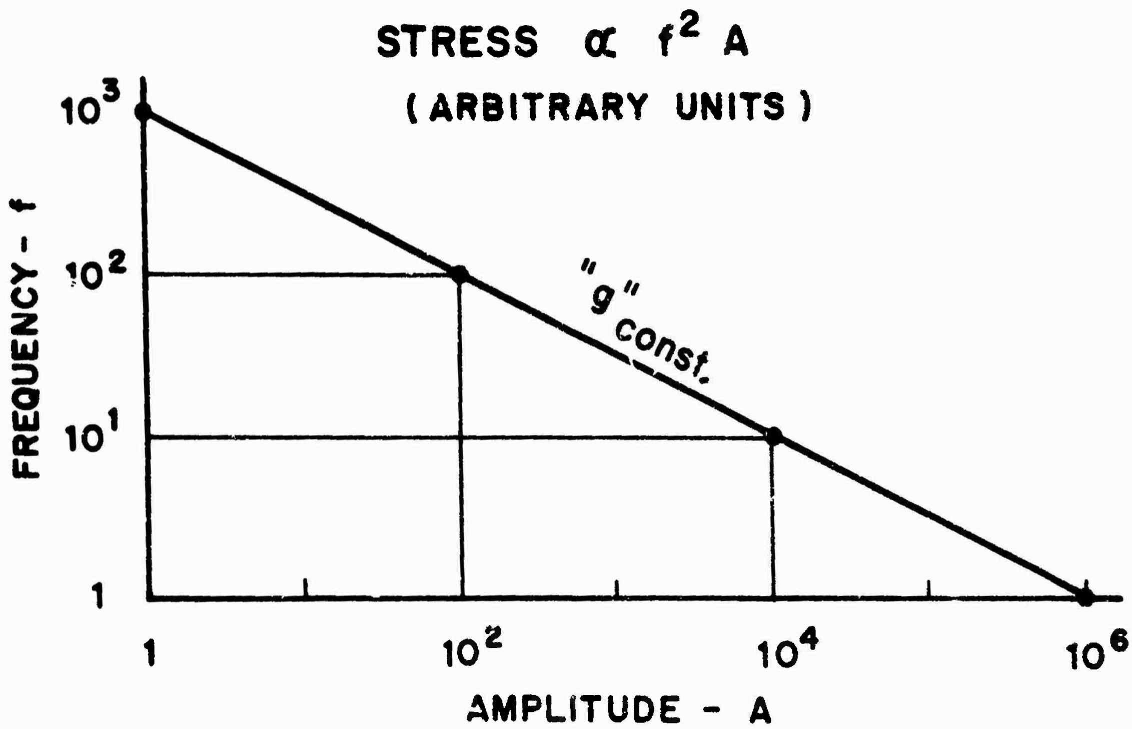


FIGURE 6

A constant "g" force, seen as stress factor, as a function of frequency and amplitude of a vibrating motion

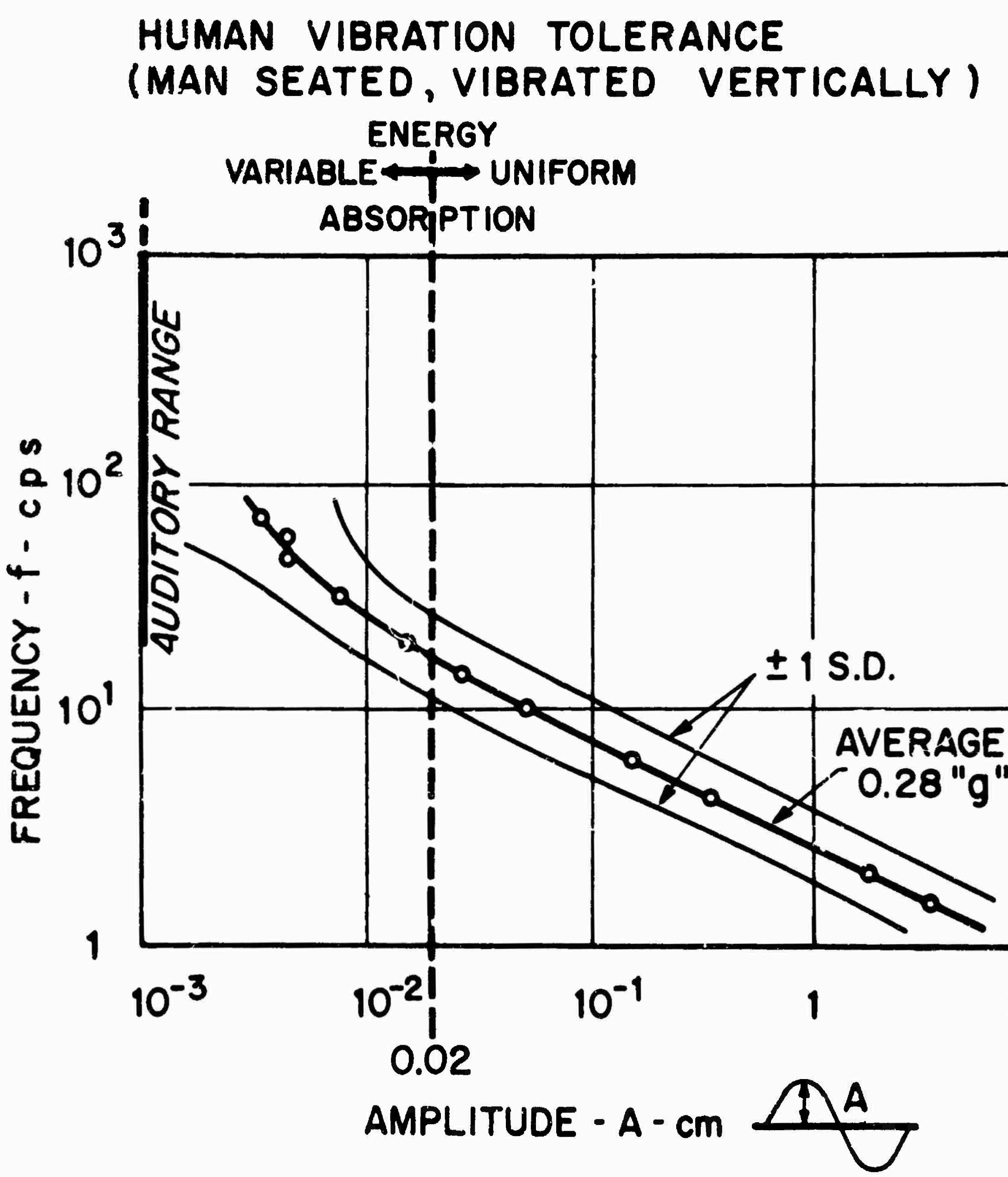
HUMAN VIBRATION TOLERANCE
(MAN SEATED, VIBRATED VERTICALLY)
ENERGY
VARIABLE
UNIFORM
ABSORPTION
AUDITORY RANGE
FREQUENCY - f - cps
10³
10²
10¹
1
± 1 S.D.
AVERAGE
0.28 "g"
10⁻³
10⁻²
10⁻¹
1
10¹
0.02
AMPLITUDE - A - cm
A

FIGURE 7

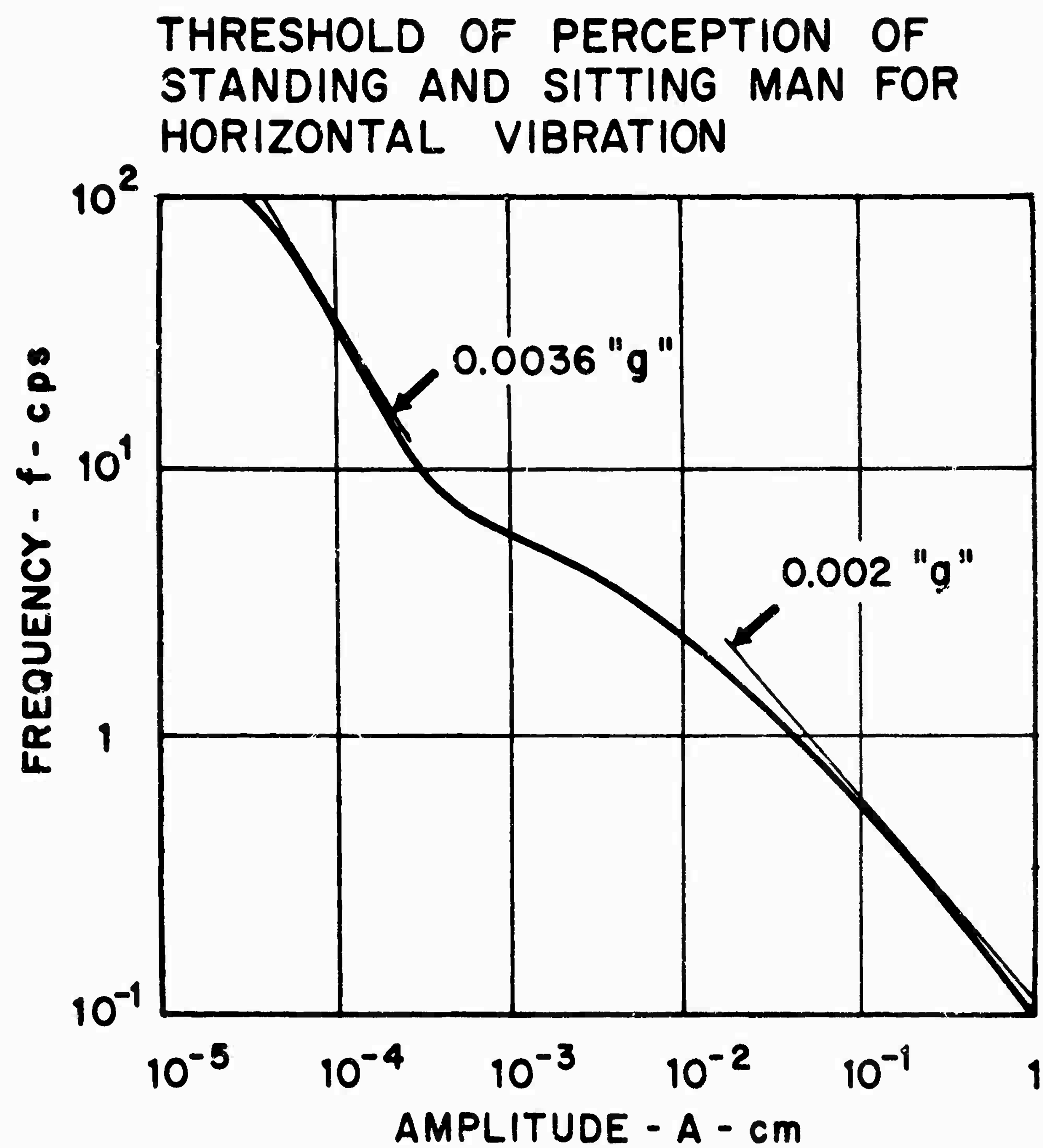
THRESHOLD OF PERCEPTION OF STANDING AND SITTING MAN FOR HORIZONTAL VIBRATION
FREQUENCY - f - cps
10^2
10^1
1
10^-1
0.0036 "g"
0.002 "g"
10^-5
10^-4
10^-3
10^-2
10^-1
1
AMPLITUDE - A - cm

FIGURE 8

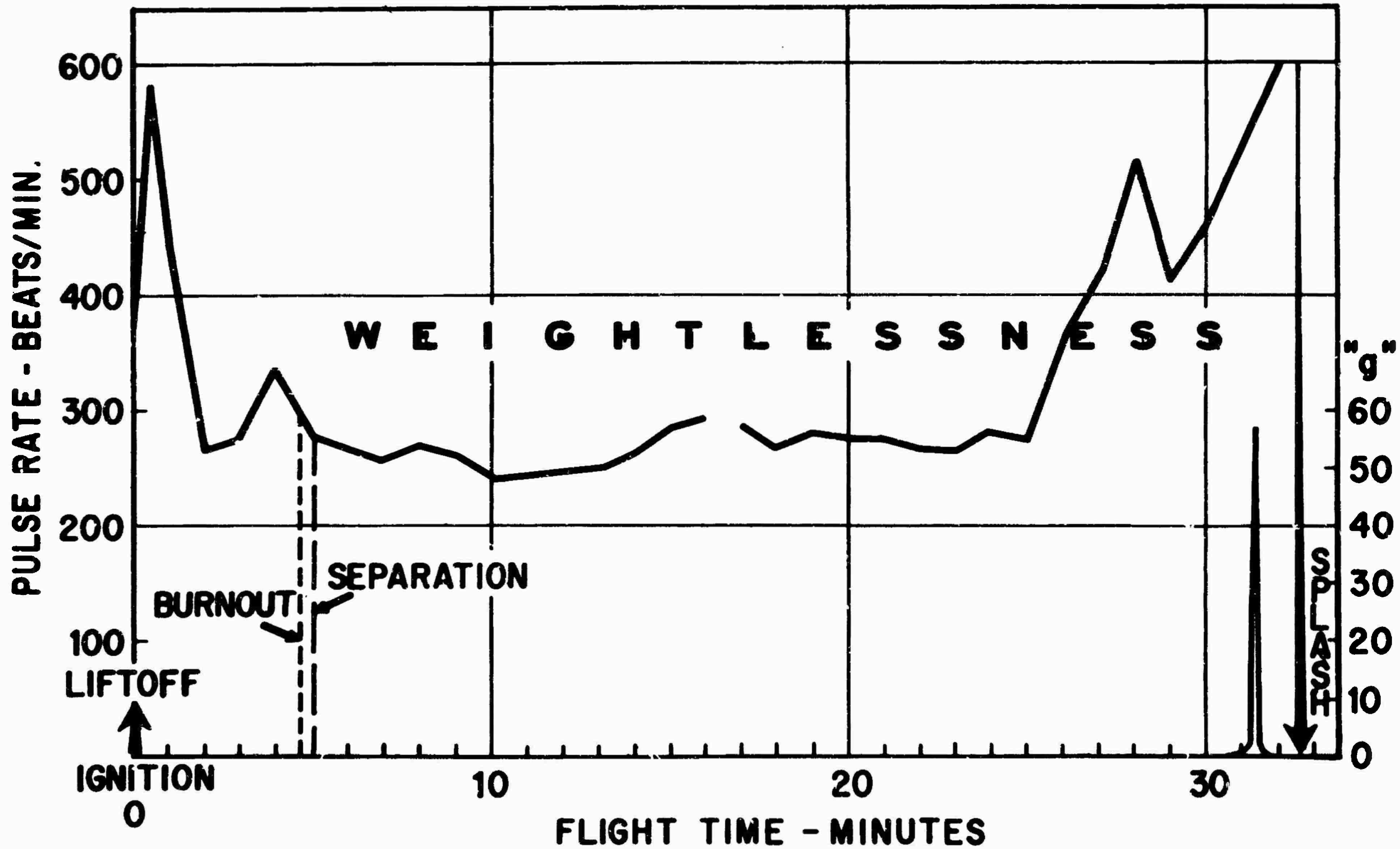


FIGURE 9

Pulse rate of a mouse recorded during a ballistic flight

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LECTURES IN AEROSPACE MEDICINE

# RADIOBIOLOGICAL EXPERIMENTS IN DISCOVERER SATELLITES

Introduction by

George W. Crawford, Ph.D.

Nuclear Research Officer

Radiobiology Branch

School of Aviation Medicine

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# RADIOBIOLOGICAL EXPERIMENTS IN DISCOVERER SATELLITES

by

George W. Crawford, Ph.D.

## I. INTRODUCTION

Over a year ago, Colonel John E. Pickering, Director of Medical Research, School of Aviation Medicine (SAM), called a group of SAM scientists together and challenged us to develop meaningful biological and dosimetric space experiments. This diverse combination of professional disciplines, by careful laboratory studies, produced the compact packages flown aboard the Discoverer Satellites.

You will meet three of the team members as they present part of this report. Other members include Captain Loren C. Logie, First Lieutenant Joseph S. Pizzuto, and S/Sgt Charles M. Kohr (chemical dosimeters, foils, and film), Austin Section of the Radiobiology Branch; Dr. Jimmie L. Flume (human gamma globulin and antiserum) and Dr. John E. Prince (chick embryo tissues) of the Microbiology Branch; as well as Dr. John E. Hewitt and Mr. Jerry Campbell (nuclear track plates) of the Bioastronautics Branch. A/3C Calvin R. Dexter, B.S. in Chemical Engineering, assigned to Radiobiology, has been invaluable in all phases of the project. It has been a pleasure to work with this team of dedicated scientists.

The problems involved in developing the compact package are many and varied. Participation is on a "piggy-back, non-interference" basis.

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NOTE: This manuscript reflects the views of the author and should not be considered official Air Force policy.

This means that the package will be loaded several days before launch and then must survive the environmental conditions as they exist. In addition, the low weight and small volume allocations impose severe restrictions as to the design of the experiment.

Also the total experiment should be meaningful whether the radiation is due mainly to galactic cosmic rays with an estimated dose rate of 1 mr/hr[1] or if a major solar flare should occur. D. H. Robey[2] has estimated that the flare of 10 May 1959 would have given an unshielded specimen an effective biological dose between 8,544 and 43,740 rem during its 29.5-hour period.

Working within these limitations, the SAM team packed the small aluminum can, 2-7/8" ID and 7" long, supplied by the Lockheed Missile and Space Division for Discoverer XVII with:

a. Biological Specimens

(1) One conjunctival human cell culture (in Rose chamber).

(2) One synovial human cell culture (in Rose chamber).

(3) Six 2 ml ampules containing Bacterial Spores of Clostridium Sporogenes (NCA, Putrefactive Anerobe 3679).

(4) Six 2 ml ampules containing algae.

(5) One package human serum fraction II-3 (human gamma globulin).

(6) One package rabbit antiserum specific for fraction II-3.

b. Physical Dosimeters

(1) Three types of chemical dosimeters.

(2) Four packages of alanine.

(3) Two packages of albumin.

(4) Seven sets of Bausch and Lomb silver-activated phosphate glass rods. Each set contained 3 rods, one unshielded, one with a .002" Al shield and one with a .006" lead shield.

(5) One package of Kodak neutron sensitive film Type A.

(6) Three step plate packages of Ansco 552 film sets.

(7) Five nuclear track plates.

(8) One Antimony foil.

The Discoverer XVIII can differed in that it contained 8 different tissue cultures in 2 ml glass ampules instead of only two, each in a heavy Rose chamber. Two neurospora—nuclear track plate packages—were also added. The detailed list follows:

Contents of SAM capsule flown on Discoverer XVIII -

Section #1
- 1 neutron film pack
- 4 chemical dosimeters (2 lead wrapped)
- 2 alanine packets
- 2 ampules of spores
- 2 552 film strips
- 4 glass needle sets
- 1 gold foil

Section #2
- 1 step plate & film in X-Y plane
- 1 step plate & film in Y-Z plane
- 1 step plate & film in X-Z plane
- 2 552 film packages
- 4 ampules of spores
- 3 ampules of tissue (nerve)
- 3 ampules of tissue
- 6 ampules of algae
- 6 glass needle sets
- 2 alanine packets

Section #3
- 2 neurospora samples with track plates
- 2 protein plates with track plates
- 3 track plates

Section #4

5 track plates
6 ampules of spores
6 ampules of tissue
2 ampules of algae media
8 glass needle sets
2 alanine packets

Polyethylene foam was used to pack the many small items tightly in the can. The can was mounted in the Discoverer nose cone as shown in figure 2. Not a single item in either can suffered breakage or other damage from the rapid acceleration or deceleration or vibrations during flight.

## The Discoverer Satellite

At 2042 Universal Time (UT) on 12 November 1960, Discoverer XVII was boosted to near orbit altitude by an Air Force Thor rocket from a launching site at Vandenberg AFB, California (fig. 3). The Thor separated and dropped away. The Agena liquid-fuel engine was ignited and the satellite was placed on a polar orbit having a perigee of 103.1 nautical miles, an apogee of 538 nautical miles, and a period of 96.44 minutes. In the Discoverer series, the Lockheed Agena Satellite is 19 feet long and five feet in diameter.

On Monday, 14 November 1960, on the thirty-first orbit, the satellite ejected its 300-pound nose cone over the Pacific Ocean near Hawaii (fig. 4). Reverse rockets slowed the nose cone so that it would not be disintegrated by the high temperature generated by the air friction on re-entry into the atmosphere (fig. 5). At 50,000 feet, a parachute opened to float the capsule gently down. At 9,500 feet, 500 miles northeast of Honolulu, an Air Force C-119 used a trapeze-like

device to catch the capsule. This was the second air catch and the third Discoverer recovered from orbit.

Discoverer XVIII was launched at 2020 UT on 7 December 1960 and recovered by aerial catch at 2342 UT on 10 December 1960 after 48 orbits. Its polar orbit had a perigee of 125.7 nautical miles, an apogee of 332.1 nautical miles, and a period of 93.67 minutes.

The two flights differed in three major respects. Discoverer XVII made 31 orbits as compared to 48 orbits for Discoverer XVIII. The orbit of XVII carried it further from the earth than did the orbit of XVIII. Finally, a 3+ solar flare had occurred over 7 hours before the launching of XVII.

## The Solar Flare

The solar flare of 3+ magnitude was detected at 1325 UT on Saturday, 12 November 1960. As there is available a very limited amount of information concerning the flare, only a tentative description of the event can be given at this time. Neutron monitor data indicating the proton flux having energies above 1 Bev have been received from the neutron monitors at Chicago, Illinois[3]; Durham, New Hampshire; Mount Washington, New Hampshire[4]; and at Deep River, Ontario, Canada[5]. Discoverer XVII missed the initial surge of Bev protons but was launched at the height of the second surge (fig. 6). The satellite was on orbit with the possibility of exposure to about one-half of the total +Bev proton flux.

Harold Leinbach[5] of the Geophysical Institute at the University of Alaska, has been kind enough to share the following very preliminary

conclusions based on ionospheric absorption studies. The low energy particles (E < 150 Mev) did not reach their maximum total flux until between 2000 and 2400 UT, 12 November 1960. The two recoveries of absorption designated by "x's" on figure 6 represent a mid-day recovery of absorption at College and do not reflect an extra-terrestrial decrease of cosmic rays. After 0200, 13 November, the flux decreased slowly, remaining at a high level for many hours. Recovery is indicated late on 15 November. The neutron monitor data indicates a return to normal level with respect to Bev protons by 2000 UT, 13 November. Thus Discoverer XVII was on orbit with the possibility of exposure to over 90% of the protons having energies less than 150 Mev.

It is hoped that when the final reports are available from the various neutron monitors, balloon and rocket flights, and ionospheric absorption studies, it will be possible to draw a more complete picture of the solar flare which can be correlated with the radiation measurements and effects on the biological specimens of the SAM biopack.

## ACKNOWLEDGMENT

The members of the SAM Discoverer team wish to express their deep appreciation to Major General Otis O. Benson, Jr., Colonel Robert H. Blount, Colonel John E. Pickering, and Dr. Roland B. Mitchell of the School of Aviation Medicine for their strong support and great assistance to this project. We also wish to thank Lt. Colonel Edward L. Cole, Captain Bruce W. Pinc, and Captain A. W. Johnson of the Air Force Ballistic Missile Division, as well as Mr. George Minalga and Mr. Robert E. Watson of the Lockheed Missile and Space Division for making this study possible.

## Bibliography

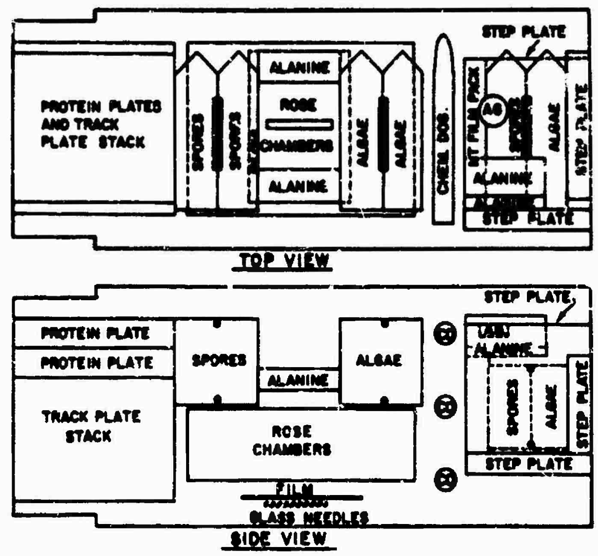
[1]Lee, J. C. Private Communication. Lockheed Missile and Space Division, Sunnyvale, California.

[2]Robey, D. H. Radiation Shield Requirements for Two Large Solar Flares. Astronautica Acta VI, 206-224 (1960).

[3]Simpson, J. A. Private Communication. The Enrico Fermi Institute, The University of Chicago, Chicago, Illinois

[4]Lockwood, J. A. Private Communication. Department of Physics, The University of New Hampshire, Durham, New Hampshire.

[5]Leinbach, Harold. Private Communication. Geophysical Institute at the University of Alaska, College, Alaska.




DISCOVERER XVII SAM BIOPACK

FIGURE 1

LOCATION OF SAM BIOPACK IN DISCOVERER XVII

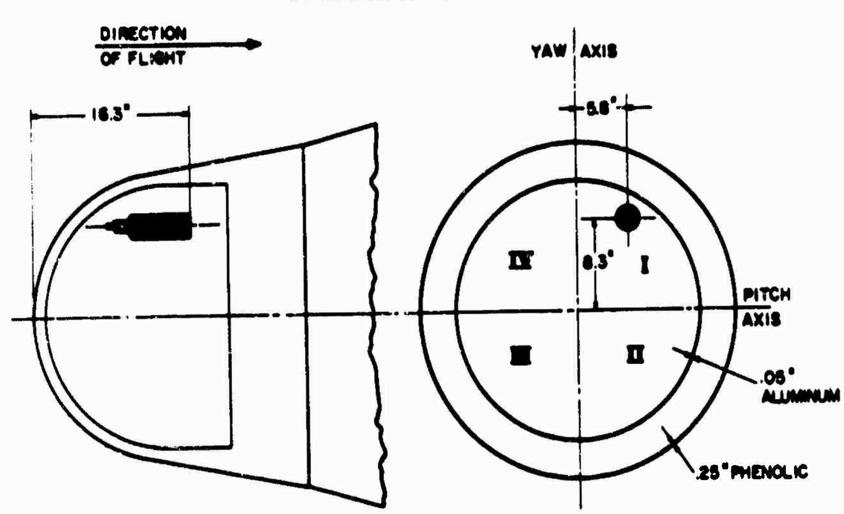



FIGURE 2

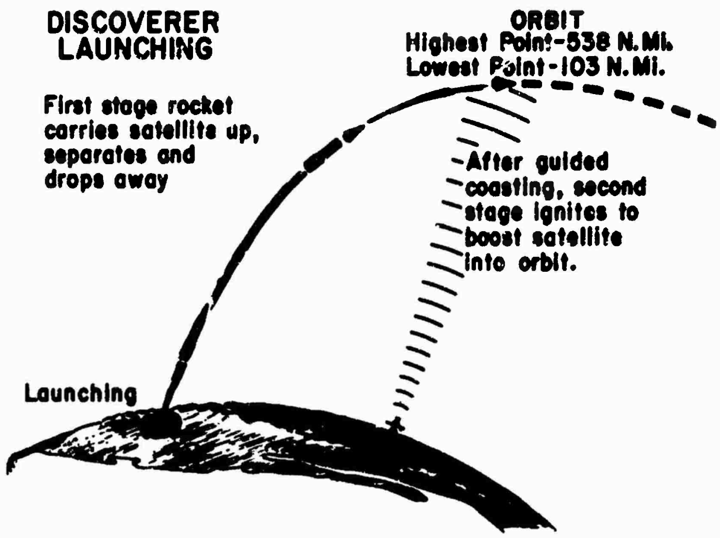



FIGURE 3

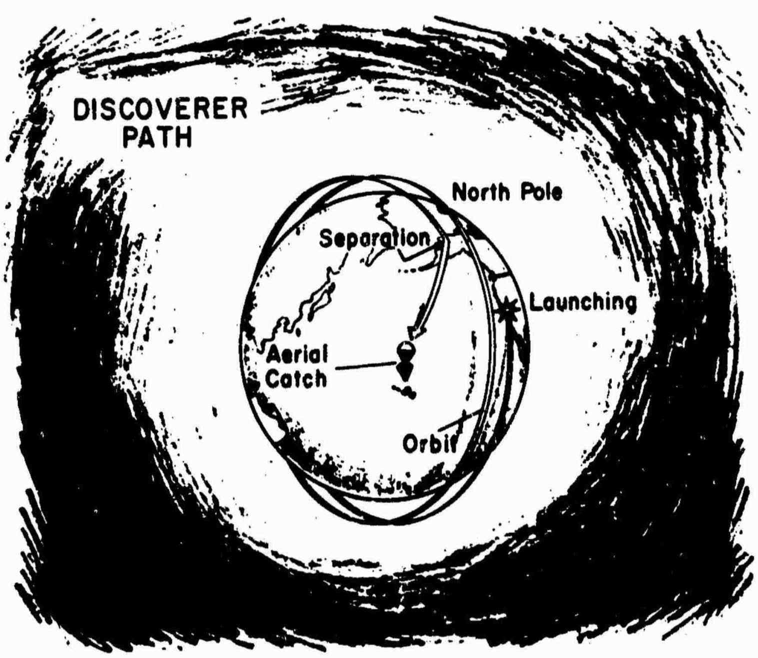



FIGURE 4

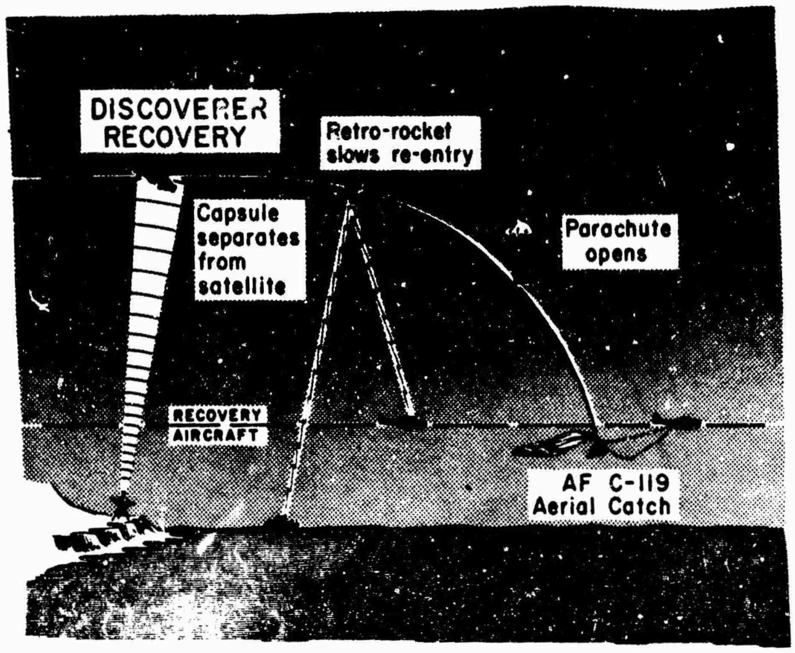



FIGURE 5

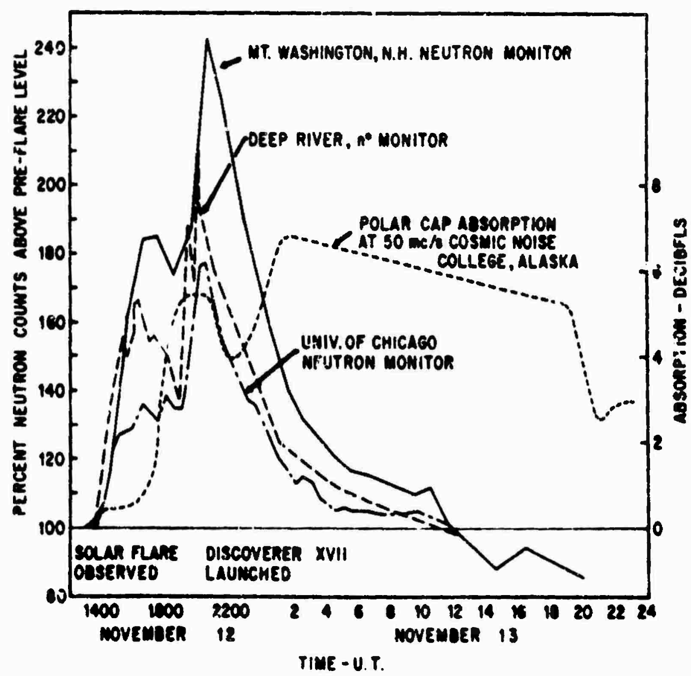
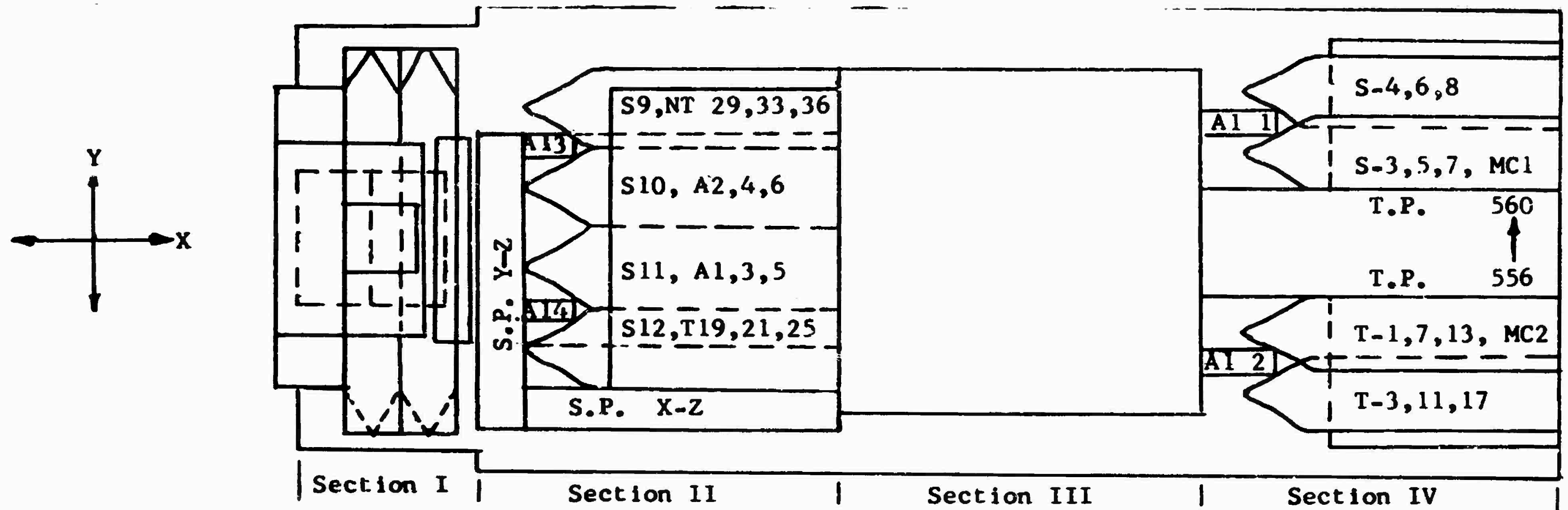
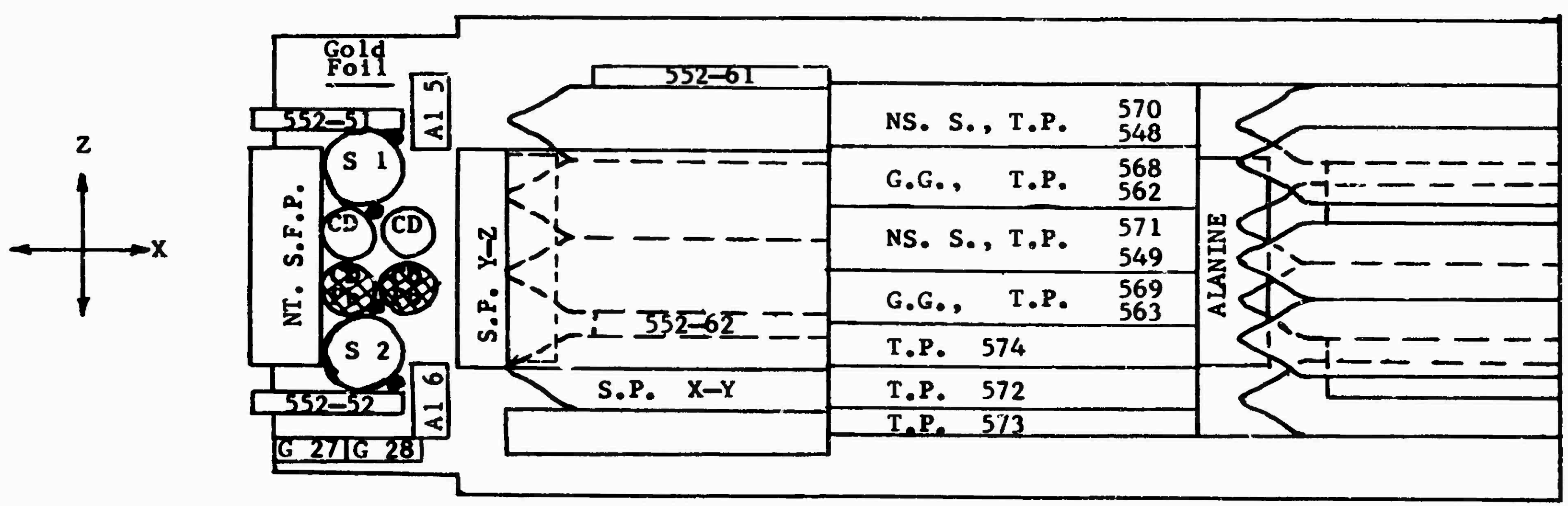



FIGURE 6




TOP VIEW

DISCOVERER XVIII SAM BIOPACK




SIDE VIEW

FIGURE 7



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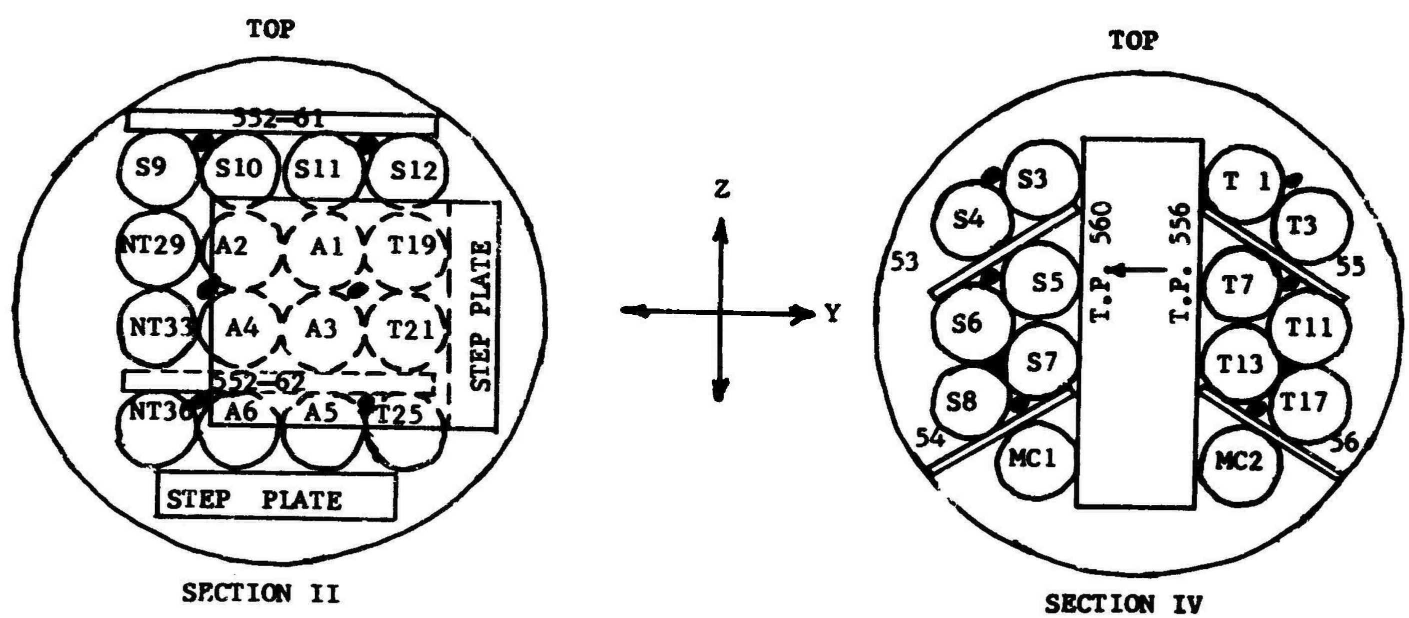


DISCOVERER XVIII SAM BIOPACK

FIGURE 8

Symbol Code for Discoverer XVIII Figures 7 and 8.

| | | |
|---|---|---|
| A. | - | Algae |
| Al. | - | Alanine |
| C.D. | - | Chemical Dosimeter |
| G. | - | Glass Chip Dosimeter |
| G.G. | - | Gamma Globulin |
| NS.S. | - | Neurospora Spores |
| NT. | - | Nerve Tissue |
| NT. S.F.P. | - | Neutron Sensitive Film Pack |
| S. | - | Spores |
| S.P. | - | Step Plate |
| T. | - | Tissue |
| T.P. | - | Track Plate |
| 552 | - | X-ray Film |

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# LECTURES IN AEROSPACE MEDICINE

## RADIOBIOLOGICAL EXPERIMENTS IN DISCOVERER SATELLITES

### I. Physical Dosimetry

Presented by

George W. Crawford, Ph.D.

Nuclear Research Officer

Radiobiology Branch

School of Aviation Medicine

# RADIOBIOLOGICAL EXPERIMENTS IN DISCOVERER SATELLITES

## I. Physical Dosimetry

By

George W. Crawford, Ph.D.
Joseph S. Pizzuto, First Lieutenant, USAF
Loren C. Logie, Captain, USAF
Calvin R. Dexter, Airman Third Class, USAF
Charles M. Kohr, S/Sgt., USAF

## INTRODUCTION

Under controlled conditions in a laboratory with a known radiation field and adequate instrumentation, it is possible to achieve radiation dose measurements within reasonable experimental error. In contrast the problems and conditions involved in measuring radiation doses inside the small SAM can aboard the Discoverer satellites actually preclude completely satisfactory measurements. Obviously, the dose which normally might be as low as a few millirads[1], could be as high as several thousand RAD in the event of a solar flare[2]. Additionally, the dose absorbed from the mixed radiation field could have a broad energy spectrum.

Space limitations and the lack of power sources or telemetry apparatus for the package limited one considerable in the choice of dosimeters and dictated somewhat the type of measurements to be made. The vehicle was not scheduled to carry counters, hence no direct measurements could be made on the primary radiations.

The package had to be able to survive a period of at least 10 days between packing and measurement. During this period it would undergo

NOTE: This manuscript reflects the views of the author and should not be considered official Air Force policy.

all of the shock, vibration, and temperature changes involved in air delivery, mounting, launching, recovery, and air return. Finally, we imposed the requirement that a minimum of two independent measurements must be achieved at each dose level.

Absorbed dose is defined as the amount of energy imparted to matter by ionizing radiation per unit mass of irradiated materials at the place of interest. It must be remembered that dose measurement is indirect in that one measures the <u>response</u> of a specific system, i.e., the density of silver deposited by development of film, the creation of free radicals, the activation of nuclei, the change in pH, or the creation of stable luminescence centers. This response may be calibrated at a specific energy of known radiation but the response of a dosimeter usually varies both with the type and the energy of the ionizing radiation. Further, if the calibration radiation field is homogenous and has a limited energy spectrum, the calibration is quite meaningful. However, in a heterogenous field having a broad energy spectrum, it is mandatory that the types of radiations present be identified and if possible, the energy spectrum of each determined before the response of a dosimeter can be translated into a meaningful dose measurement.

DESCRIPTION OF THE EXPERIMENT

Fully realizing that the results at best would be limited in their interpretation, the selected dosimeters were as follows:

1. Nuclear Track plates: Ilford G-5 emulsion (Range: up to 2 x $10^6$ tracks per $cm^2$)

2. Kodak neutron sensitive NTA film. (Range: up to $2 \times 10^6$ tracks per $cm^2$)

3. Dupont 502 emulsion film. (Range: 0.4 to 20 RAD)

4. Dupont 510 emulsion film. (Range: 2 to 100 RAD)

5. Bausch and Lomb silver activated glass rods. (Range: 10 to $10^4$ RAD)

6. Two-phase tetrachloroethylene chemical dosimeter. (Range: 10 to $10^6$ RAD)

7. Single-phase $CO_2$ free trichloroethylene chemical dosimeter. (Range: 25 to 250 RAD)

8. Alanine (Range: $10^2$ to $10^5$ RAD)

9. Single-phase trichloroethylene chemical dosimeter. (Range: 150 to $10^6$ RAD)

10. Albumin. (Range: above $10^{11}$ free radicals per gram).

11. Antimony foil. (Range:* above 700 protons and/or neutrons per $cm^2$ per sec.)

12. Gold foil. (Range:* above $2 \times 10^3$ neutrons per $cm^2$ per sec).

Identification of the ionizing radiations was attempted from the study of tracks in the nuclear track plates and in the NTA film. The existence of x-rays were to be detected using Dupont 502 and 510 emulsion film in step plates (Region A, unshielded; Region B, 0.020" Al. shielding; Region C, 0.020" of Al. plus 0.010" Cu; Region D, 0.020" Al. plus 0.020" Cu.) and by using B & L glass rods in sets of three (one unshielded, one with an aluminum foil shield, and the third with a lead foil shield).

* Based on the most probable reactions that will occur at these energies (probably n, 2n or p, pn reactions).

In each experiment, many sets of glass rods were located at strategic places in the can. A three dimensional array of 552 film-step plates was placed in the third section of the can. The other dosimeters, where possible, were placed in locations most likely to give some meaningful measurement.

DATA AND RESULTS

The following data are presented as the best analysis to date. However, additional calibration work is in progress.

| Dosimeter | Radiation Dose in RADs Equivalent 730 Mev Protons: Discoverer 17 | Discoverer 18 |
|---|---|---|
| 1. Two-phase tetrachloroethylene chemical | 30.7 | No response |
| 2. Single-phase $CO_2$ free trichloroethylene | 25.0 | No response |
| 3. Single-phase trichloroethylene | below 150.0 | No response |
| 4. Dupont 552 film packs (measured in unshielded region) | | |
| a. Under Rose chambers (bottom of can) | 33.0 | Response but too low to be measured accurately |
| b. x-y plane (bottom of can) | 22 | |
| c. x-z plane (left side of can) | 16 | |
| d. y-z plane (end of can) | 27 | |
| 5. Alanine | below 100 | No response |

Table I

Dosimeter Response Tranlated into RADs Equivalent 730 Mev Protons

TABLE II

Response of Glass Rods to Cosmic Radiation Encountered by Discoverer XVII

| Set # | Rod # | Shielding | Response | RAD Equivalent Dose 730 Mev Protons |
|---|---|---|---|---|
| 858 | 858 | | 5.5 | 31. |
| | 859 | Al. | 6.0 | |
| | 860 | Pb. | 8.1 | |
| 934 | 934 | | 5.0 | 27. |
| | 935 | Al. | 5.2 | |
| | 936 | Pb. | 7.1 | |
| 937 | 937 | | 5.5 | 31. |
| | 938 | Al. | 7.0 | |
| | 939 | Pb. | 14.0 | |
| 1001 | 1001 | | 5.7 | 32.5 |
| | 1002 | Al. | 6.6 | |
| | 1003 | Pb. | 7.2 | |
| 1004 | 1004 | | 5.2 | 29. |
| | 1005 | Al. | 5.6 | |
| | 1006 | Pb. | 7.4 | |
| 1007 | 1007 | | 4.8 | 26. |
| | 1008 | Al. | 6.1 | |
| | 1009 | Pb. | 7.5 | |
| 1010 | 1010 | | 4.2 | 21. |
| | 1011 | Al. | 5.0 | |
| | 1012 | Pb. | 10.0 (chipped) | |

The calibration of the response of the B & L glass rods to 730 Mev protons is now in analysis, therefore, the dose measurements based on the response (creation of stable luminescence centers) in the rods is given in Roentgens equivalent Cobalt 60 gamma rays. (See Table II). On the Discoverer XVII flight, all of the unshielded rods record a smaller response than do the shielded rods. The aluminum covered rods have a response intermediate between the unshielded rods and the rods having a lead shield. None of the rods aboard Discoverer XVIII received a measurable dose.

The single value given as the "dose" measured using the 552 type film is based on the density of the unshielded portion of the film. Actually this region was the least dense area on the film. In each case, the region under the .020" Al. shield was slightly darker than the unshielded region. Regions C and D under the combination Al-Cu shields remained the darkest portions of the film. We interpret the higher density under the shielding to be due to secondary radiations produced in the shielding material. (See Figure 1)

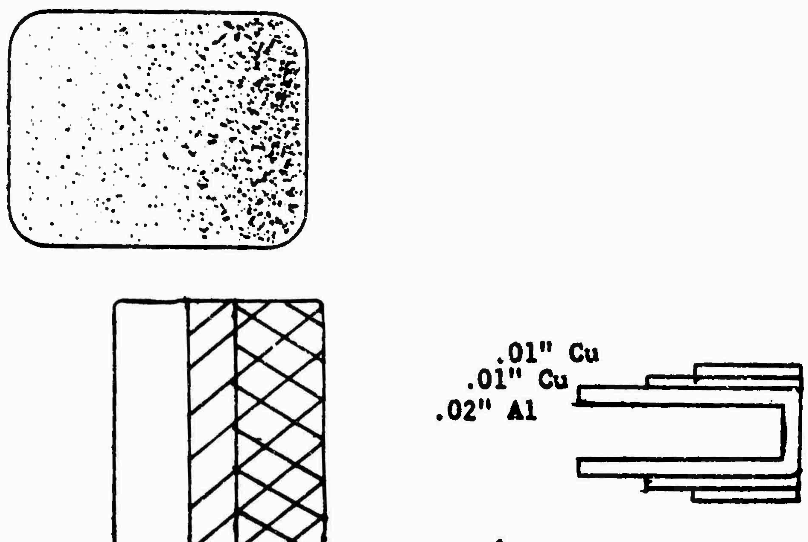

Table III summarizes the data relating the number of tracks counted in the NTP and NTA emulsions. Many additional weeks of work remain before the study of these plates can be completed. Only composite track densities are being reported at this time.

| Emulsion | Orientation | Number of Tracks per $cm^2$ Discoverer XVII | Discoverer XVIII |
|---|---|---|---|
| Ilford G-5 | x-y plane | over exposed | 56 to 80 x $10^4$ |
| Ilford G-5 | x-z plane | -------- | 80 to 128 x $10^4$ |
| Kodak NTA | y-z plane | 16 to 20 x $10^4$ | 7 to 11 x $10^4$ |

Table III

It is interesting to note that the tracks found in the NTA film aboard Discoverer 17 have an average higher ionization density than the tracks observed in the NTA film aboard Discoverer XVIII, an indication that the higher flux recorded in 17 might be due to low energy solar protons.

## CONCLUSIONS

By careful analysis of the data, we are seeking to: 1) Identify the ionizing radiations producing the response in the dosimeters and 2) to measure a meaningful dose. The study is still incomplete and the following observations are subject to change.

A. Discoverer 17:

1. Based on reports 1,3,4,5 concerning the solar flare we can safely assume that the can was exposed to a large flux of protons. Using

730 Mev proton calibrations as the basis for the estimate, this flux was of the order of magnitude of 6 to 8 x $10^8$ protons per square cm.

2. The response measurements on both the film and the glass rods reveals that the lead covering on the glass needles, the lead sandwiched between the nuclear track plates, the lead wrappings on the NTA film and the copper shielding of the step plates were a source of secondary radiation, presumably x-rays. For example, in the case of the glass rods, assuming the glass to be ten times more responsive to the secondary x-rays than to the primary protons, the higher reading of rod # 860 as compared to rod # 858 corresponds to an estimated additional x-ray dose of about 2 roentgens.

3. No bremsstrahlung from electrons being stopped in the walls of the can was detected.

4. No evidence of primary electron irradiation was found.

5. Neutron (recoil proton) tracks were observed starting in the NTA plates but the numbers were neither great nor probably significant.

6. Calibrations in progress using 730 Mev protons does establish that variations in film density and variations in the response of the glass needles indicate a measurable dose variation throughout the can. Analysis of this variation continues.

7. Disregarding local increases in dose from secondaries created in the heavy metals, the measured radiation dose ranges from 16 to 33 RAD equivalent 730 Mev protons.

B. Discoverer XVIII:

1. The total flux ranges from 56 to 128 x $10^4$ tracks per square cm.,

depending on the location and orientation of the plate. Identification of particles is obviously incomplete.

2. No bremsstrahlung was detected.

3. Neutron (recoil proton) tracks were observed in the NTA and NTP emulsions but the numbers were small and are probably not significant.

4. The dose is much too low for accurate measurement, but estimated to be between 0.4 and 0.6 RAD equivalent 730 Mev protons.

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[1]Lee, J. C. Private Communication. Lockheed Missile and Space Division, Sunnyvale, California.

[2]Robey, D. H. "Radiation Shield Requirements for Two Large Solar Flares." Astronautica Acta VI, 206-224 (1960).

[3]Simpson, J. A. Private Communication. The Enrico Fermi Institute, The University of Chicago, Chicago, Illinois.

[4]Lockwood, J. A. Private Communication. Department of Physics, The University of New Hampshire, Durham, New Hampshire.

[5]Leinbach, Harold. Private Communication. Geophysical Institute at the University of Alaska, College, Alaska.

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LECTURES IN AEROSPACE MEDICINE

RADIOBIOLOGICAL EXPERIMENTS IN DISCOVERER SATELLITES

II. CLOSTRIDIA SPORE LABILIZATION: A BIOLOGICAL SYSTEM TO QUANTITATE RADIATION

Presented by

Major Irving Davis, USAF, MSC
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# RADIOBIOLOGICAL EXPERIMENTS IN DISCOVERER SATELLITES

## II. CLOSTRIDIA SPORE LABILIZATION: A BIOLOGICAL SYSTEM TO QUANTITATE RADIATION

By

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One of the primary concerns in man's "conquest of space" is radiation: what kinds?-- how much?-- how to protect man? For some time now, science has recognized the basic concept of the "unity of life" (1) and studies with one phylum have provided logical answers to similar questions regarding other forms of life. It is in this manner that microorganisms, with their inherent rapidity of reproduction and other advantageous attributes, have been used as a biological tool to provide us with knowledge about physiology, biochemistry, biophysics, and genetics that is, in many respects, universally applicable. It is with this philosophy that we turned to microbiology several years ago to seek some answers regarding the biological effects of space radiations.

### MICROBIAL GENETIC SYSTEM

The first attempts to study the biological effects of cosmic radiation utilized a microbial genetic system. The ability of cosmic radiation to act as a mutagenic agent, theoretically, can be determined by selecting one genetically controlled characteristic of the parent microbial cell and quantitatively determining the spontaneous and induced mutation rates. In 1956, lyophilized cultures of a streptomycin-dependent strain of the bacterium, *Escherichia coli*, (2), and an adenineless mutant of the mold, *Neurospora crassa* (3), were sent aloft in one of the balloon space flights. In 1959, fluid

NOTE: This manuscript reflects the views of the author and should not be considered official Air Force policy.

cultures of the same bacterium reached a maximum altitude of 280,000 feet aboard a "Little Joe" rocket. In 1960, this bacterial genetic system was employed on a series of four balloon space flights and attained peak altitudes of approximately 135,000 feet for approximately twelve hours (4). All of these data and additional laboratory studies attest to the relatively high energies required to produce a genetic mutation at a given locus - a phenomenon which appears to be general in nature.. From these investigations, it was concluded that, with the altitudes and flight times of the current space probes, the use of a microbial genetic system to detect the biological effects of space radiations was not practical because of insufficient sensitivity of the genetic marker.

## CLOSTRIDIUM SPORE LABILIZATION SYSTEM

An attempt was made to find an alternate biological system for space radiation research in place of the microbial genetic system. The requisites for the biological entity were (1) ability to withstand the temperature extremes, prolonged storage, and rigors of handling normally encountered during space experimentation; and (2) provide a sensitive biological indicator that would be altered in a quantitative manner when exposed to radiation. It had been reported by Wynne and co-workers (5) that when heat stabile Clostridia spores are incubated at 75° C. in the presence of caramelized glucose, some become heat labile and are rapidly killed at this temperature. Those spores surviving the caramelization action then may be quantitatively determined by incubating them at

37° C. in nutrient substrate permitting their germination into vegetative cells with the resulting formation of visible colonies.

This Clostridia spore labilization system, based upon a physiologic-metabolic function of the cell, measures changes in the rate of spore labilization produced in the presence of stimulatory (or inhibitory) agents. Evidence from studies with chemical mutagens has established the feasibility of this system as a sensitive indicator of physiologic-metabolic activity (6). Other lines of evidence have demonstrated the similarities of action that exist between the chemical mutagens and the physical mutagens, e.g., ionizing radiations (7, 8). It was reasoned that radiations might react with the Clostridia spore labilization system in the same manner as chemical mutagens and, therefore, provide a means of quantitating and correlating space radiations with microbiological activity. The rationale for this system is diagrammed in figure 1.

Experimentation employing laboratory-controlled radiations have confirmed the validity of this hypothesis (9). This paper reports results obtained utilizing the Clostridia spore labilization system on biological specimens recovered from the Discoverer XVII and XVIII Satellites space flights.

## MATERIALS AND METHODS

Cultures: Clostridium sporogenes, ATCC No. 7955 (NCA, "Putrefactive Anaerobe" 3679) was used. A working suspension containing $4 \times 10^3$ cells per ml. was prepared using sterile demineralized distilled water. Aliquots of this working suspension were delivered to

ampules (Kimble No. 12011, 2.0 ml. size) and heat sealed. All sealed ampules were checked for possible leakage by vacuum technique. No leakage was detected. Sealing procedure was not injurious to the spores. All cultures were stored at 5° C. until used.

Caramelized Glucose: A 10% solution of glucose in 0.2 M $K_2HPO_4$ was autoclaved for 80 minutes at 121° C/15 psi. This stock caramelized glucose solution was diluted 1:50 with sterile demineralized distilled water, adjusted with 1N NaOh to pH 7.5 and used as the working solution. Nine ml. aliquots of the caramelized glucose working solution was employed in the spore-treatment procedure.

Germination Count Medium: This substrate has been formulated in detail by other workers (10). Basically, it consists of yeast extract, thioglycollate supplement, starch, $K_2HPO_4$, $NaHCO_3$ and agar. The Prickett tubes of medium were maintained in a water bath (45° C) until inoculated with the cell suspension. Following inoculation and solidification of the medium, an anaerobic seal was provided by overlaying the medium surface with thioglycollate supplement agar.

Post-Flight Experimental Protocol: Each ampule was opened aseptically. Two ml. of the spore suspension was diluted in a tube to 8.0 ml. with sterile demineralized distilled water. This tube of spore suspension was placed in a water bath until the cells had remained at 75° C. for five minutes. Following this, one ml. aliquots of the spore suspension were delivered into each of six tubes previously having reached temperature equilibrium at 75° C. in a water bath. Three of these tubes contained 9.0 ml. of the

caramelized glucose working solution (treatment); the other three tubes contained 9.0 ml. of 0.2 M $K_2HPO_4$ (controls). After specific time intervals, two 1.0 ml. aliquots were removed from each tube and each aliquot inoculated into a Prickett tube of germination count medium. Treatment tubes withdrawals were made at 30, 45 and 90 minutes. Control tubes were analyzed at 0, 30, 45 and 90 minutes. Zero time was the time of spore aliquot inoculation into the treatment or control tubes. All germination count medium tubes were incubated at 37° C. Colony counts were made at 24 to 48 hours.

## DISCOVERER XVII RESULTS

Six biological ampules were aboard the flight package; an equal number of spore ampules served as ground controls, accompanying the flight package to the vehicle launch point and returning to the laboratory post-flight. All ampules were selected randomly from a homogeneous group of sealed ampules. Laboratory control ampules also were taken from this group. Data appear in table I. It is noted that each figure in the table is the average count of the number of spores that were capable of germinating and forming visible colonies in the germination count medium. Each average value represents triplicate aliquots from each ampule and duplicate germination counts for each aliquot, i.e., the average of six colony counts. The values shown in parentheses in this table are the percent of labile spores for each indicated time period. These spores were affected by the caramelized glucose treatment at 75° C and failed to germinate when subsequently placed in appropriate

nutrient substrate at 37° C. A statistical evaluation was carried out with these data. Statistically significant results were considered significant at the 5 percent level.

The pre-flight handling operations and environment encountered had very little or no effect on the spore system. This is observed by comparing table I results for ground control and lab control ampules at zero time and each of the post-treatment times. Variability among ampules in each group was not significantly different between the two groups. These results indicate the reliability and repeatability of the Clostridia spore labilization system, i.e., the uniform quantitative deleterious effect of caramelized glucose treatment upon spores normally stable at 75° C.

The percent labilization results from table I for the two control groups were each pooled. The similarity of data for ground control and lab control is graphically expressed in figure 2. The percent labilization flight data, as shown in figure 2, was handled in a different fashion. Plotting of the percent labilization versus treatment time data for each ampule revealed that the curves of the six ampules could be combined reasonably into three divisions. A statistical evaluation ("t" test) was carried out by comparing each ampule at each time period against the ground controls. At 30 minutes treatment time, statistically significant difference was observed in flight ampules 1 ($p < .05$), 3 and 4 ($p < .01$); differences in the other data were not statistically significant (N.S.).

After 45 minutes treatment time, all the flight ampules showed statistically significant difference at the 1% level except ampules 1 ($p < .05$) and 5 (N.S.). Following 90 minutes treatment with caramelized glucose, the spores in flight ampules produced statistically significant data from the controls ($p < .01$) with the exception of ampules 1 and 3 (N.S.). It may be concluded from these data in figure 2 that the spores in all the ampules recovered from the Discoverer XVII satellite flight showed some degree of inhibition of the post-flight caramelized glucose treatment of the spores (percent labilization) compared to the ground controls. Any comparison between a similarly numbered flight and ground control ampule is meaningless.

Another phenomenon occurring to the Discoverer XVII flight ampules is shown in figure 3. The flight ampule numbers are arranged, from left to right, in the physical order they occupied aboard the SAM recoverable biopack (11). All columns represent the number of residual spores that germinated and produced visible colonies on appropriate nutrient substrate. These data represent spore survival counts of the flight and ground control ampules following the Discoverer flight and after return to the laboratory but prior to caramelized glucose treatment. The figures within the flight ampules columns are percent survivals (100% survival is the average of the ground control ampules, 102 spores). Normally, these percent survivals would be a reflection of the lethality that occurred to the spores. This may not be true here, as will be discussed later.

Further, it appears that a "lethal" (or "survival") gradient is expressed by the six flight ampules. Their physical positioning within the SAM recoverable biopack supports this gradient possibility. However, it is premature to state that this "lethal" gradient is a reflection of radiation lethality. According to Crawford (11), radiation dosimetry appeared to indicate a measurable dose variation throughout the biopack. Further, the minimum amount of radiation required to show lethality in Clostridia spore suspensions is of the order of 100,000 to 200,000 rep. (12, 13). Other explanations are suggested for this "lethal" gradient phenomenon without any attempt to evaluate their importance. Space environmental factors other than radiations may be involved, e.g., vibration, temperature, etc. Inoculation of cell clumps into germination count medium may be responsible. Finally, the possibility that high energy, heavy particles may be involved should be explored.

DISCOVERER XVIII RESULTS

The recoverable biopack aboard the Discoverer XVIII contained twelve ampules of Clostridia spores. Four ground control ampules accompanied the flight ampules to Vandenberg Air Force Base, California, and were returned with them to the laboratory after the flight. Flight and ground control ampules were maintained at approximately 5° C during pre- and post-flight times until they were subjected to post-flight caramelized glucose treatment in the laboratory. During the flight period, ground control ampules were kept at ambient room temperature (approx. 25° C). The four laboratory control ampules remained at approximately 5° C until analyzed

along with the flight and ground control ampules. All ampules were selected randomly from a homogeneous group.

Data appear in table II. These data were treated in the same manner as previously described in the text for table I data. The pre-flight handling operations and environment encountered had very little or no effect on the spore system. This is observed by comparing table II results for ground control and lab control ampules at zero time and each of the post-treatment times. Percent labilization variability between ampules in both of these groups was not statistically significantly different. Therefore, the average percent labilization results from table II for the two control groups were graphed as indicated in figure 4.

The flight data for the Discoverer XVIII was processed similarly to that previously described for the Discoverer XVII, i.e., individually for each ampule and collectively as a group. Percent labilization of the flight group was not statistically significant when compared to the combined control groups. However, when this same comparison was made with regard to post-flight caramelized glucose treatment time, statistical significance was observed ($p < .05$). On this basis the percent labilization data for each ampule at each treatment time was evaluated against similar data for the combined controls. The analysis indicated that four of the twelve flight ampules (nos. 2 and 7 ($p < .05$); 3 and 12 ($p < .01$)) showed statistically significant differences from the controls after 90 minutes caramelized glucose treatment. The curves in figure 4

show this separation of the flight ampule group into two divisions. The inhibition of percent labilization shown by these four flight ampules at 90 minutes, although small, is apparent.

An attempt was made to relate the number of recovered spores in each flight ampule after flight and return to the laboratory but prior to caramelized glucose treatment with its physical positioning within the recoverable biopak. The type of relationship referred to in the Discoverer XVII results was not apparent in the Discoverer XVIII results.

## DISCUSSION

What factor(s) is responsible for the quantitative inhibition of labilization shown by the flight ampules in Discoverer XVII (figure 2) and Discoverer XVIII (figure 4)? Recent studies in our laboratory with this Clostridia spore labilization system have shown that when similar spores are exposed to laboratory-controlled ionizing radiations and subsequently treated with caramelized glucose, the labilization effect is quantitatively inhibited (9). To date this effect of radiation on the spore system has been demonstrated using x-ray, gamma, beta, and alphas. A preliminary dose versus percent labilization curve for alpha radiation (910 Mev), shown in figure 5, typifies these quantitative results. The equivalent radiation dose received by the flight ampules in each Discoverer mission may be approximated from such a laboratory-controlled radiation curve. As a matter of convenience one might use, as a standard measure,

the "percent inhibition of labilization." This quantity is expressed by the equation

$$\% \text{ Inhibition} = \frac{L_1 - L_2}{L_1} \times 100$$

where $L_1$ is the percent of labilization caused by the caramelized glucose itself, and $L_2$ is the percent of labile spores as a result of the interaction between the caramelized glucose and another agent added to the experimental system. The percent labilization results obtained with 910 Mev alpha (figure 5) have been re-expressed using the above equation. The resulting curve, percent inhibition of labilization as a function of dose, appears in figure 5.

The percent inhibition of labilization expressed by the flight ampules at 90 minutes in the Discoverer XVII flight may be calculated (figure 2). Flight ampule 5 showed a 38 percent inhibition; ampules 2, 4, and 6 revealed an average inhibition of labilization of 71 percent. Using this latter figure, the equivalent effective dose of 910 Mev alpha that will produce 71 percent inhibition of the test system is approximately 860 rad (figure 5).

Similar calculations may be made for the Discoverer XVIII flight ampules. The four flight ampules that showed significant data after 90 minutes treatment inhibited labilization 12 percent (figure 4). This inhibition is equivalent to approximately 60 rad 910 Mev alpha (figure 5).

Both of the Discoverer experiments lend support to the usefulness of the Clostridia spore as a biological entity for space study.

Those requisites established earlier in this paper appear to be fully met by the Clostridia spore labilization system. The cells are hardy, endure the rigors of pre- and post-flight handling, and alter themselves in a definable manner in the presence of radiation.

A comparison between the two Discoverer flights revealed a quantitative difference between the radiations recorded (11). According to the best information present at this writing, Discoverer XVII recorded approximately 40-45 rad x-ray equivalent; Discoverer XVIII registered less than 0.1 rad x-ray equivalent. The response of the bacterial spores to the test system also reflects this quantitative difference between the two Discoverer flights as already discussed. The magnitude of this difference expressed by the biological material is not as great as the radiation difference between the two flights. Since neither of these two radiation indexes, i.e., physical dosimetry and biological dosimetry have been completely worked out, cautious reliance must be placed on either. However, it seems appropriate and imperative that a base line for comparison be established for both of these radiation detection and measurement systems. Accomplishment of this objective is being pursued at this time with 730 Mev protons, a major constituent of space radiations.

To the knowledge of this investigator, this is the first microbiological system that has been returned from space, the positive results of which possibly may be correlated with positive radiation dosimetry. This suggests that the Clostridia spore labilization system may find use as a biological index of space radiation hazards.

ACKNOWLEDGEMENTS

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TABLE I

Number of Residual Clostridium sporogenes spores (P.A. 3679) Following Caramelized Glucose Treatment at 75° C. for Indicated Time Periods.

| AMPULES | | TIME (minutes) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 30 | | 45 | | 90 | |
| | | Control | Control | Treatment | Control | Treatment | Control | Treatment |
| Discoverer XVII Flight Nos. | 1 | 105* | 101 | 94 (6%)** | 101 | 76 (25%) | 99 | 13 (87%) |
| | 2 | 90 | 87 | 76 (13%) | 86 | 74 (14%) | 84 | 55 (35%) |
| | 3 | 110 | 100 | 101 (0%) | 97 | 77 (21%) | 100 | 12 (88%) |
| | 4 | 78 | 70 | 68 (3%) | 71 | 68 (4%) | 71 | 56 (21%) |
| | 5 | 71 | 75 | 59 (21%) | 76 | 45 (41%) | 72 | 33 (54%) |
| | 6 | 62 | 62 | 55 (11%) | 58 | 57 (1%) | 62 | 49 (21%) |
| Ground Control Nos. | 1 | 102 | 100 | 83 (17%) | 99 | 50 (49%) | 96 | 11 (89%) |
| | 2 | 106 | 106 | 90 (15%) | 105 | 59 (44%) | 98 | 19 (81%) |
| | 3 | 101 | 99 | 79 (20%) | 97 | 45 (54%) | 98 | 9 (91%) |
| | 4 | 96 | 98 | 84 (14%) | 95 | 59 (38%) | 95 | 11 (88%) |
| | 5 | 105 | 103 | 84 (18%) | 100 | 46 (54%) | 99 | 10 (90%) |
| | 6 | 100 | 101 | 86 (15%) | 98 | 52 (47%) | 97 | 17 (82%) |
| Lab Control Nos. | 1 | 109 | 104 | 83 (20%) | 101 | 39 (61%) | 98 | 7 (93%) |
| | 2 | 108 | 100 | 85 (15%) | 101 | 42 (58%) | 100 | 11 (89%) |

* Each figure represents triplicate aliquots per ampule, duplicate counts per aliquot, i.e., each figure is the average of six colony counts.

** Figures in parenthesis are the percent of labile spores at the indicated time period, i.e., $\frac{\text{control minus treatment}}{\text{control}} \times 100$.

TABLE II

Number of Residual *Clostridium sporogenes* spores (P.A. 3679) Following Caramelized Glucose Treatment at 75°C. for Indicated Time Periods

| AMPULES | | TIME (minutes) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 30 | | 45 | | 90 | |
| | | Control | Control | Treatment | Control | Treatment | Control | Treatment |
| DISCOVERER XVIII FLIGHT Nos. | 1 | 105* | 103 | 84 (18%)** | 102 | 46 (55%) | 102 | 1 (99%) |
| | 2 | 105 | 103 | 82 (20%) | 104 | 52 (50%) | 100 | 14 (86%) |
| | 3 | 106 | 106 | 86 (19%) | 102 | 48 (53%) | 102 | 22 (78%) |
| | 4 | 107 | 104 | 91 (13%) | 105 | 47 (55%) | 101 | 10 (90%) |
| | 5 | 105 | 102 | 85 (17%) | 102 | 46 (55%) | 100 | 13 (87%) |
| | 6 | 103 | 104 | 87 (16%) | 102 | 47 (54%) | 100 | 13 (87%) |
| | 7 | 110 | 107 | 87 (19%) | 103 | 48 (53%) | 104 | 15 (86%) |
| | 8 | 105 | 107 | 86 (20%) | 104 | 53 (49%) | 101 | 13 (87%) |
| | 9 | 107 | 104 | 86 (17%) | 105 | 52 (50%) | 103 | 12 (88%) |
| | 10 | 109 | 106 | 82 (23%) | 107 | 48 (55%) | 104 | 5 (95%) |
| | 11 | 107 | 108 | 87 (19%) | 106 | 47 (56%) | 104 | 9 (91%) |
| | 12 | 104 | 107 | 86 (20%) | 105 | 49 (53%) | 105 | 19 (82%) |

* Refer to Table I
** Refer to Table I

TABLE II (continued)

| AMPULES | | TIME (minutes) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0 | 30 | | 45 | | 90 | |
| | | Control | Control | Treatment | Control | Treatment | Control | Treatment |
| GROUND CONTROL NOS. | 1 | 104* | 106 | 84 (21%)** | 99 | 50 (50%) | 101 | 2 (98%) |
| | 2 | 106 | 105 | 87 (17%) | 104 | 50 (52%) | 101 | 7 (93%) |
| | 3 | 106 | 108 | 85 (21%) | 103 | 47 (54%) | 103 | 8 (92%) |
| | 4 | 110 | 104 | 85 (18%) | 109 | 46 (58%) | 105 | 4 (96%) |
| LAB CONTROL NOS. | 1 | 105 | 104 | 84 (19%) | 102 | 46 (55%) | 99 | 2 (98%) |
| | 2 | 111 | 108 | 92 (15%) | 105 | 54 (49%) | 104 | 13 (88%) |
| | 3 | 114 | 108 | 87 (19%) | 111 | 50 (55%) | 106 | 12 (89%) |
| | 4 | 110 | 107 | 87 (19%) | 106 | 48 (54%) | 106 | 6 (94%) |

* Refer to Table I

** Refer to Table I

## CLOSTRIDIA SPORE LABILIZATION: A BIOLOGICAL SYSTEM TO QUANTITATE RADIATION

NORMAL BACTERIAL SPORES
(HEAT-STABLE)

| I | II | III |
|---|---|---|
| AT 37°C SPORES GERMINATE INTO VEGETATIVE CELLS | CARAMELIZED GLUCOSE (CG) AT 75° C | IRRADIATION |
| | | ↓ |
| | ↓ | CARAMELIZED GLUCOSE AT 75°C |
| | | ↓ |
| | REDUCED NUMBER DEPENDING ON DURATION OF CG CONTACT | REDUCED NUMBER AS IN (II), BUT NOT AS GREAT FOR EQUIVALENT DURATION OF CG CONTACT |
| | ↓ | ↓ |
| | AT 37°C SPORES NOT LABILIZED GERMINATE INTO VEGETATIVE CELLS | RADIATION INHIBITS CG LABILIZATION EFFECTS |
| | | ↓ |
| | | AT 37°C SPORES NOT LABILIZED GERMINATE INTO VEGETATIVE CELLS |

FIGURE 1

Rationale of the Clostridium spore labilization system to quantitate radiation.

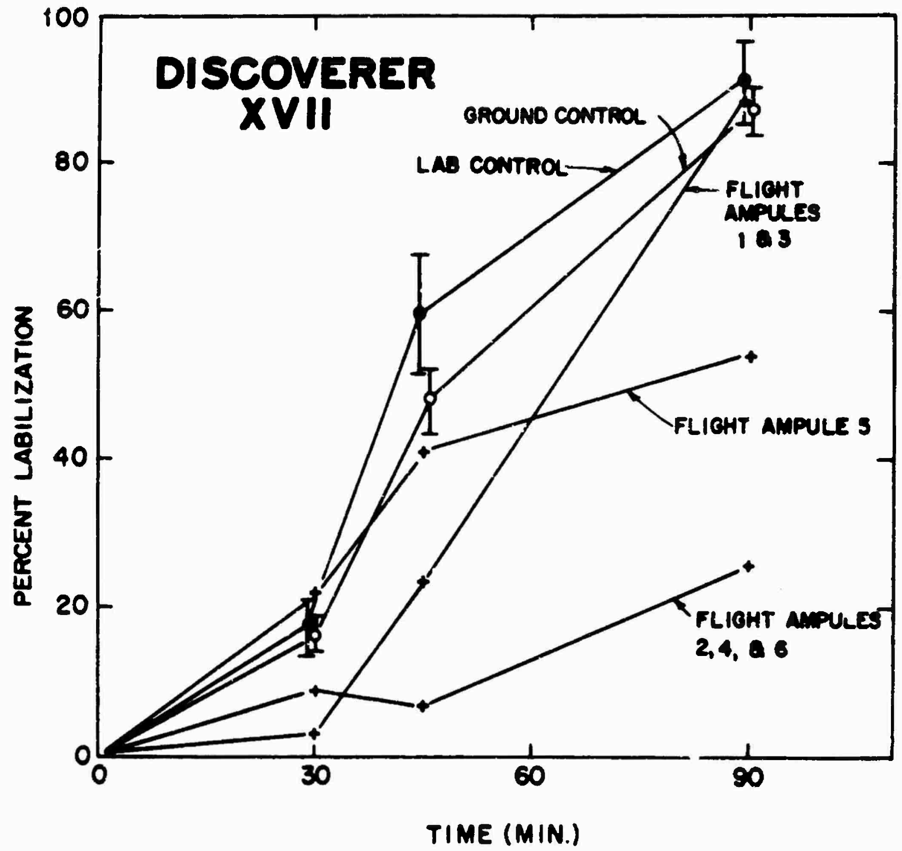


FIGURE 2

Effect of caramelized glucose treatment at 75° C for indicated time periods on post-flight Clostridium sporogenes spores (PA3679). Ground control data represent average of six ampules. Lab control data represent average of two ampules. Flight data are the average of the ampules indicated. 95% confidence limits appear in control curves.

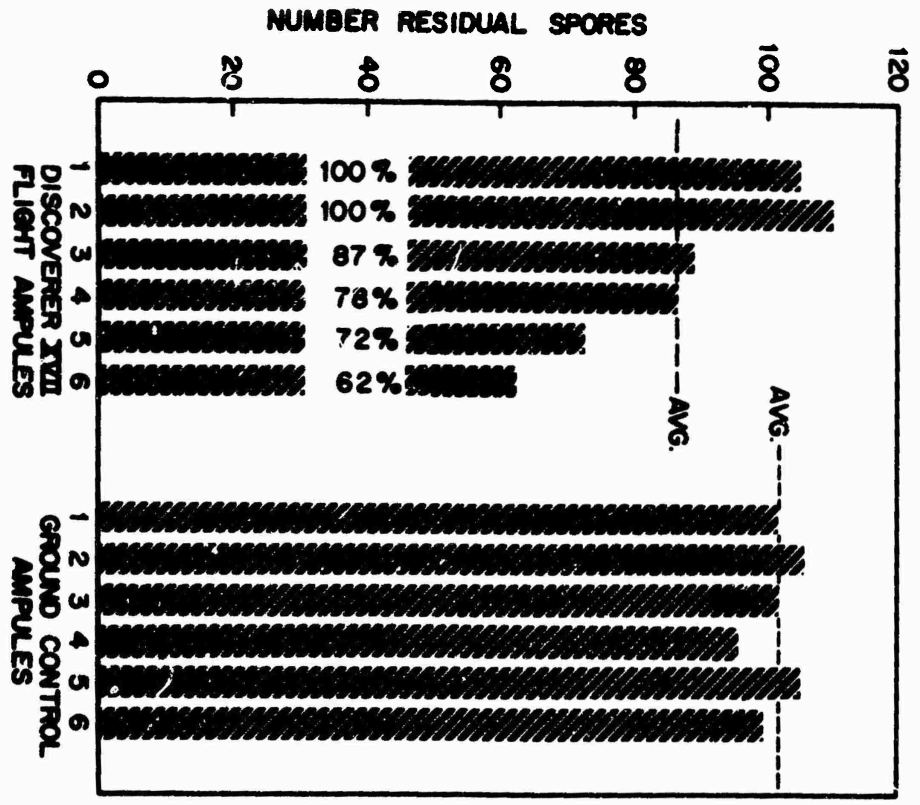


FIGURE 3

Number of residual Clostridium sporogenes spores (PA3679) recovered following the Discoverer flight and after return to the laboratory but prior to caramelized glucose treatment. Figures within bars are percent survivals. 100% survival is average of ground control ampules.

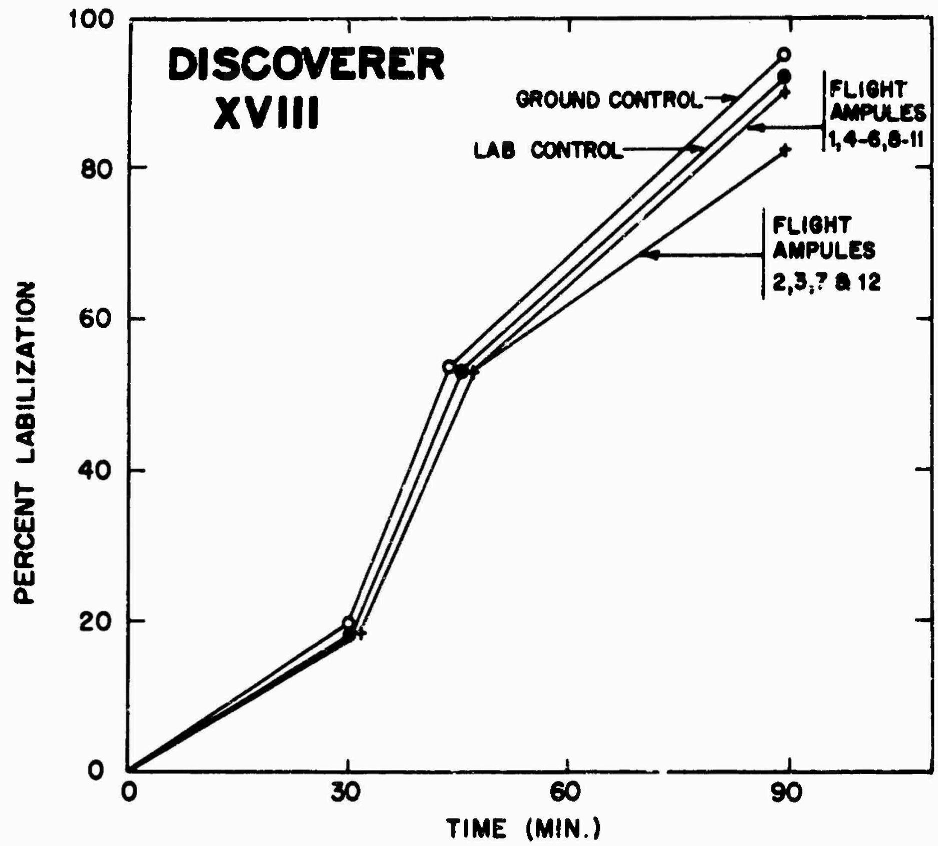


FIGURE 4

Effect of caramelized glucose treatment at 75° C for indicated time periods on post-flight Clostridium sporogenes spores (PA3679). Ground control data represent average of six ampules. Lab control data represent average of two ampules. Flight data are the average of the ampules indicated.

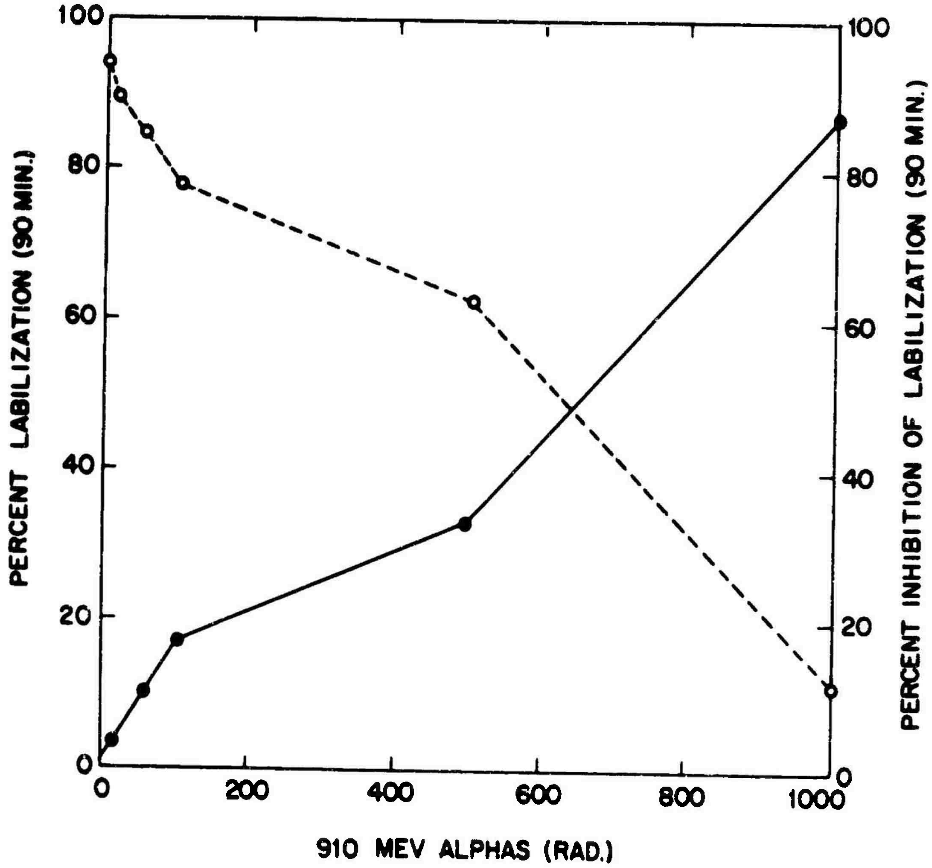


FIGURE 5

Effect of caramelized glucose treatment at 75° C for indicated time period on post-irradiated *Clostridium sporogenes* spores (PA3679). Post-irradiation survival of all dose levels was 100%.

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LECTURES IN AEROSPACE MEDICINE

# RADIOBIOLOGICAL EXPERIMENTS IN DISCOVERER SATELLITES: III. THE EFFECT OF SPACE FLIGHTS ON LIVING HUMAN CELLS ABOARD THE DISCOVERER VEHICLE

Presented by

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# THE EFFECT OF SPACE FLIGHTS ON LIVING HUMAN CELLS ABOARD THE DISCOVERER VEHICLE

by

Allan A. Katzberg

The limitations of human tolerances and adaptability to stress are largely established at the cellular level. Living mammalian cells are very sensitive to any alteration of the environment. Trauma may be induced by a wide variety of agents that may be physical (1), chemical (2 and 3) or biological (4) in nature, and may register its effect on the morphology (5 and 6) and physiology (7) of the living cells. The traumatic effect may be temporary, permanent or lethal in nature. For example, physical agents, such as irradiation can induce a chain of reactions that may ultimately produce a biochemical lesion that is permanently registered on the intrinsic genetic mechanism of the cell (3), namely the chromosome, others may register their effect on the cytoplasm and induce cytoplasmic and nuclear hypertrophy (8 and 9).

Forearmed with this knowledge, living cultures of human cells were placed on board Discoverer XVII. Two Rose chambers (fig. 1) were seeded with approximately 100,000 cells each. One contained synovial cells that originated from the synovial lining of a bone joint, the other was seeded with conjunctival cells from the conjunctival surface of the eyelid. The culture medium consisted of two c.c. of balanced salt solution and 10 percent horse serum. Three sets of such culture were prepared, one for laboratory control, one for ground control at the launching site and one for flight on Discoverer XVII.

On the 12th day after preparation the cultures participated in the space flight of Discoverer XVII. They were returned to this laboratory on the 16th day after preparation. Preliminary observations indicated that they were in an advanced state of degeneration (figs. 2-6). However, on the 12th day after their return indications of survival appeared. On the 20th day after their return, there was definite new growth in the flight cultures (figs. 7 and 8). Cells were undergoing multiplication and were moving about. It is believed that the initial degenerated appearance and the lag in recovery was largely due to exhaustion of the nutrient media in the long interval of time that elapsed before they were returned to the laboratory. Refeeding permitted the revival of some cells to occur. Since the mortality rate was approximately the same in the cultures that served as ground controls, radiation alone cannot be held to be solely responsible for the cellular damage and deaths that did occur.

This initial success, small though it may have seemed, nevertheless indicated that such living human material can survive the stresses of space flight.

Certain defects of methodology encountered in the Discoverer XVII flight were corrected for the Discoverer XVIII flight. A smaller population of 50,000 cells was suspended in 3 c.c. medium and sealed in glass ampules which also contained a small glass coverslip (fig. 9).

Seven human cell lines were employed. Five of these were normal and definitive representatives of the three embryonic germ layers and two were of neoplastic origin.

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Human cell lines

| | |
|---|---|
| Ectodermal | Amnion<br>Conjunctiva |
| Mesoderm | Sternal Marrow<br>Synovia<br>Monocytic leukemia*<br>Hela* |
| Entodermal --- | Embryonic lung |

* Neoplastic cell lines

Cultures of Avian embryonic tissue were also flown. These were the astrocytic and oligodendrogial derivatives cultured from the corpus callosum of the brain of a 10-day-old chick embryo.

All cultures were returned in good condition on the 12th day following preparation. Preliminary observation indicated a high level of viability.

No latent lag period was noted in this series of human cells on subculturing. The smaller initial population, the larger volume of medium and the shorter interval that lapsed before their return were the principal factors contributing to this good survival and immediate resumption of growth.

Some inhibition of growth initiation was noted in the cultures of the avian neuroblasts. However, since the sampling was so small it is questionable whether this can be considered to be statistically significant.

The following slides show the appearance of the various cells immediately following their return to the laboratory.

| | | |
|---|---|---|
| Conjunctiva | Control | (fig 10) |
| | Flight | (fig 11) |
| Sternal Marrow | Control | (fig 12) |
| | Flight | (fig 13) |
| Synovia | Control | (fig 14) |
| | Flight | (fig 15) |
| Hela | Flight | (fig 16) |
| Chick Neuroblasts | | (fig 17) |

The time-lapse motion picture studies are continuing as are studies on genetic characteristics as exhibited by possible chromosomal aberrations. However, as this analysis requires slow painstaking procedures, the final data will not be available for several months.

ACKNOWLEDGMENT

Acknowledgment is given to other members of the Cellular Biology Section who contributed to the prosecution of the various phases of this study, namely, Dr. J. E. Prince, A/1C A. Castro, Mr. L. Mori, and SSgt J. Mabry.

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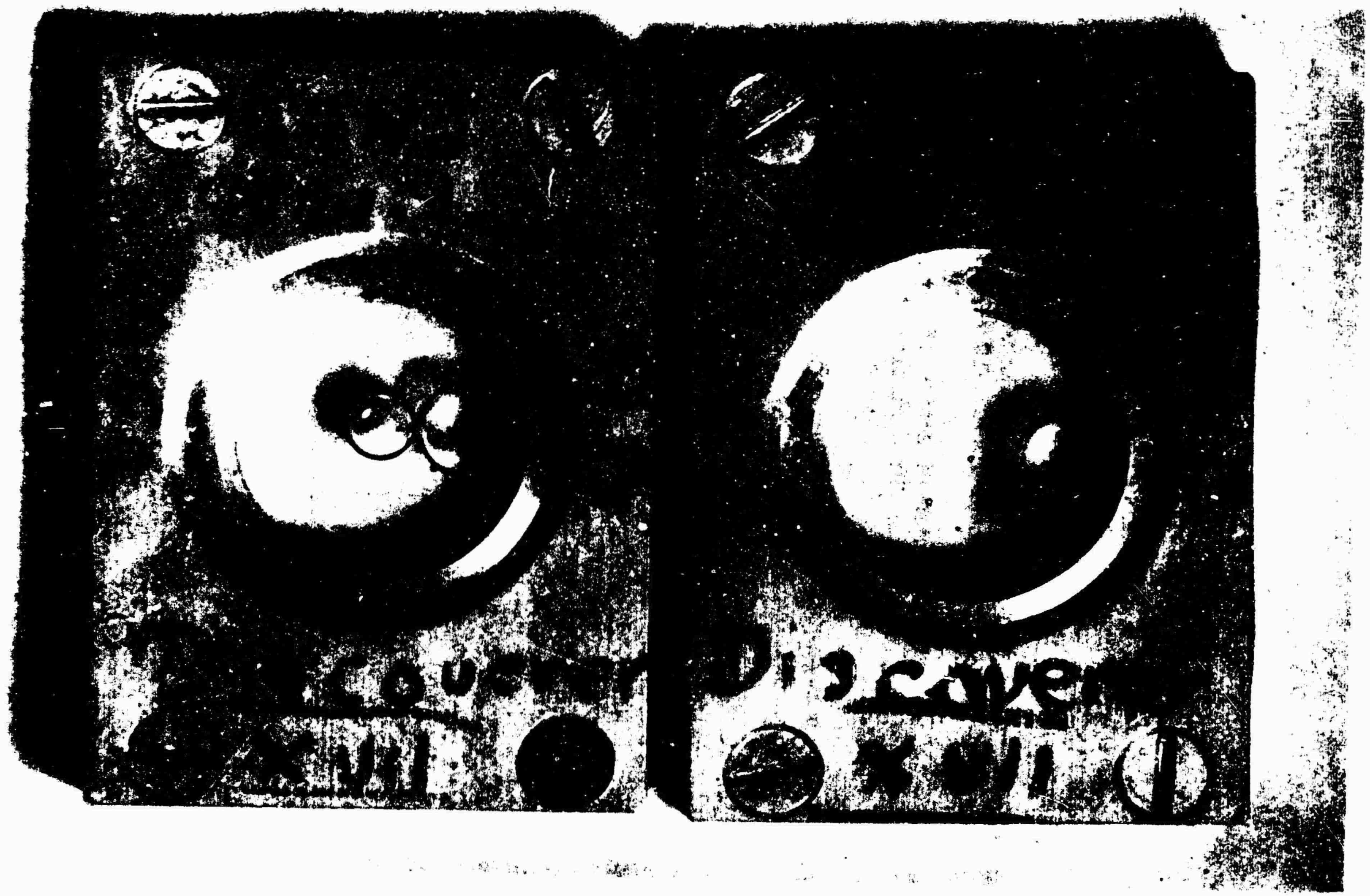

FIGURE 1

Rose chambers employed for the maintenance of living cells on the flight of Discoverer XVII.

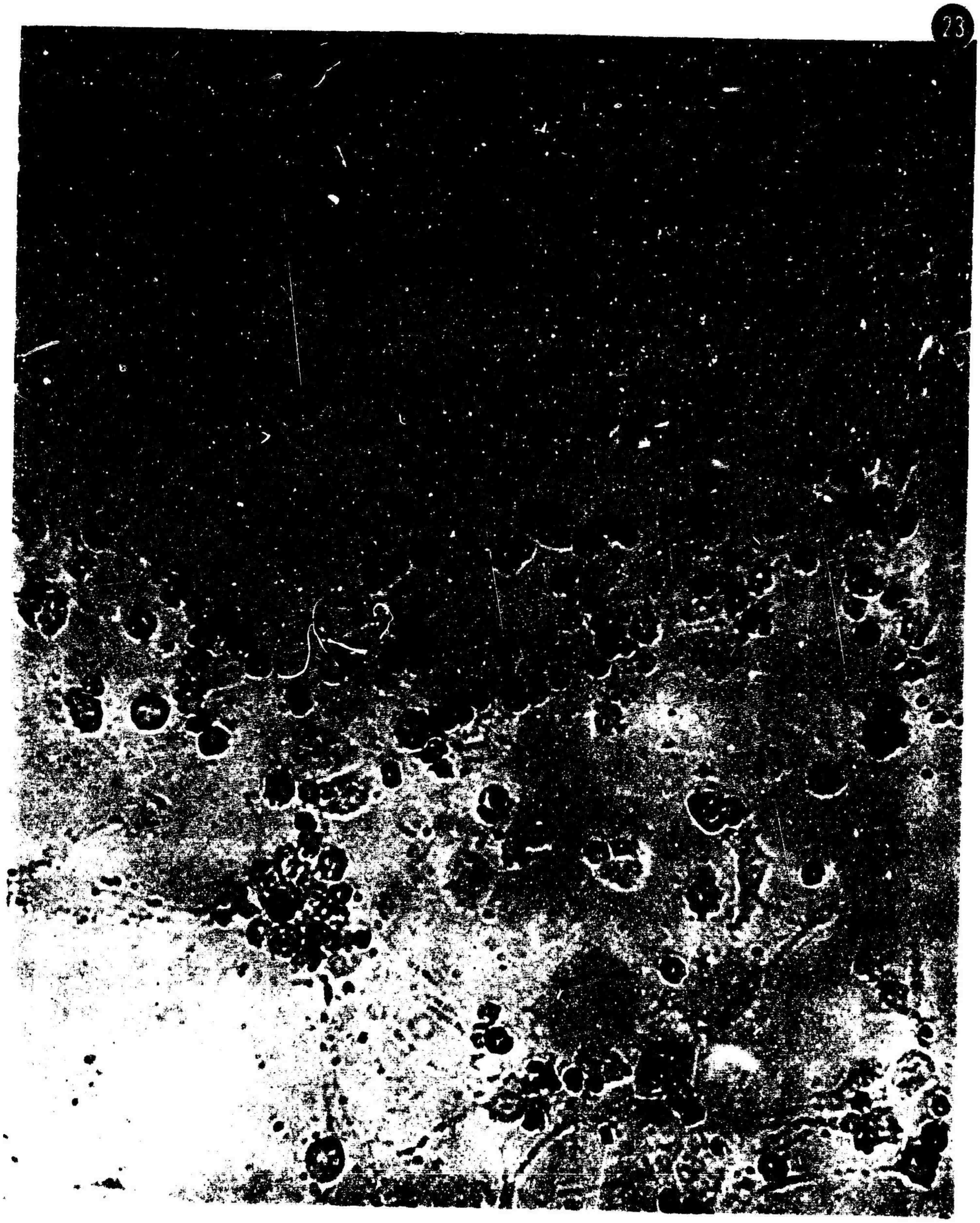

FIGURE 2

Early degenerative appearance of laboratory control culture of synovial cell. Magnification X 125.

FIGURE 3

Ground control of conjunctival cell showing granulation and rounding up as indicative of degeneration. Magnification X 500.

FIGURE 4

Flight culture of conjunctival cell showing similar degenerated condition as cell in figure 3. Magnification X 500.

FIGURE 5

Ground control of synovial cell showing similar degenerated state as indicated in figures 3 and 4. Magnification X 500.

FIGURE 6

Flight culture of synovial cell showing condition similar to figure 5. Magni_ication X 500.

FIGURE 7

Synovial cells from flight culture 21 days post-flight. Note the active proliferation. Magnification X 125.

FIGURE 8

Synovial cells from flight culture 21 days post-flight. Note the active proliferation. Magnification X 500.

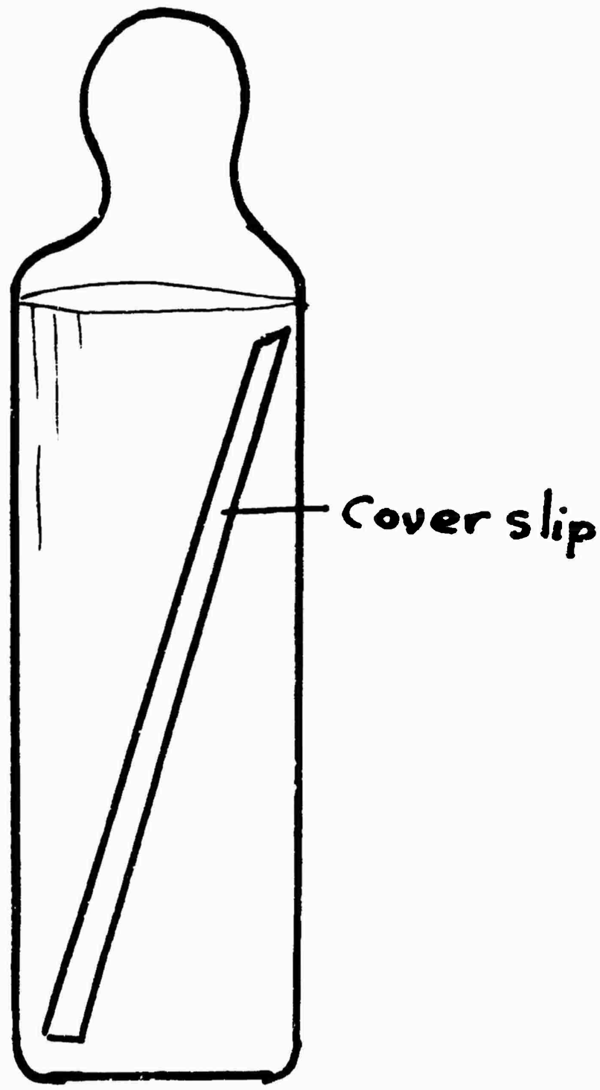


FIGURE 9

Figure of ampule with inserted coverslip as was employed for cultures on Discoverer XVIII.

FIGURE 10

Conjunctival cells of ground control cultures 12 days after preparation. May-grunwald stain. Magnification X 500.

FIGURE 11

Conjunctival cells of flight cultures 12 days after preparation - 2 days after flight. May-grunwald stain. Magnification X 500.

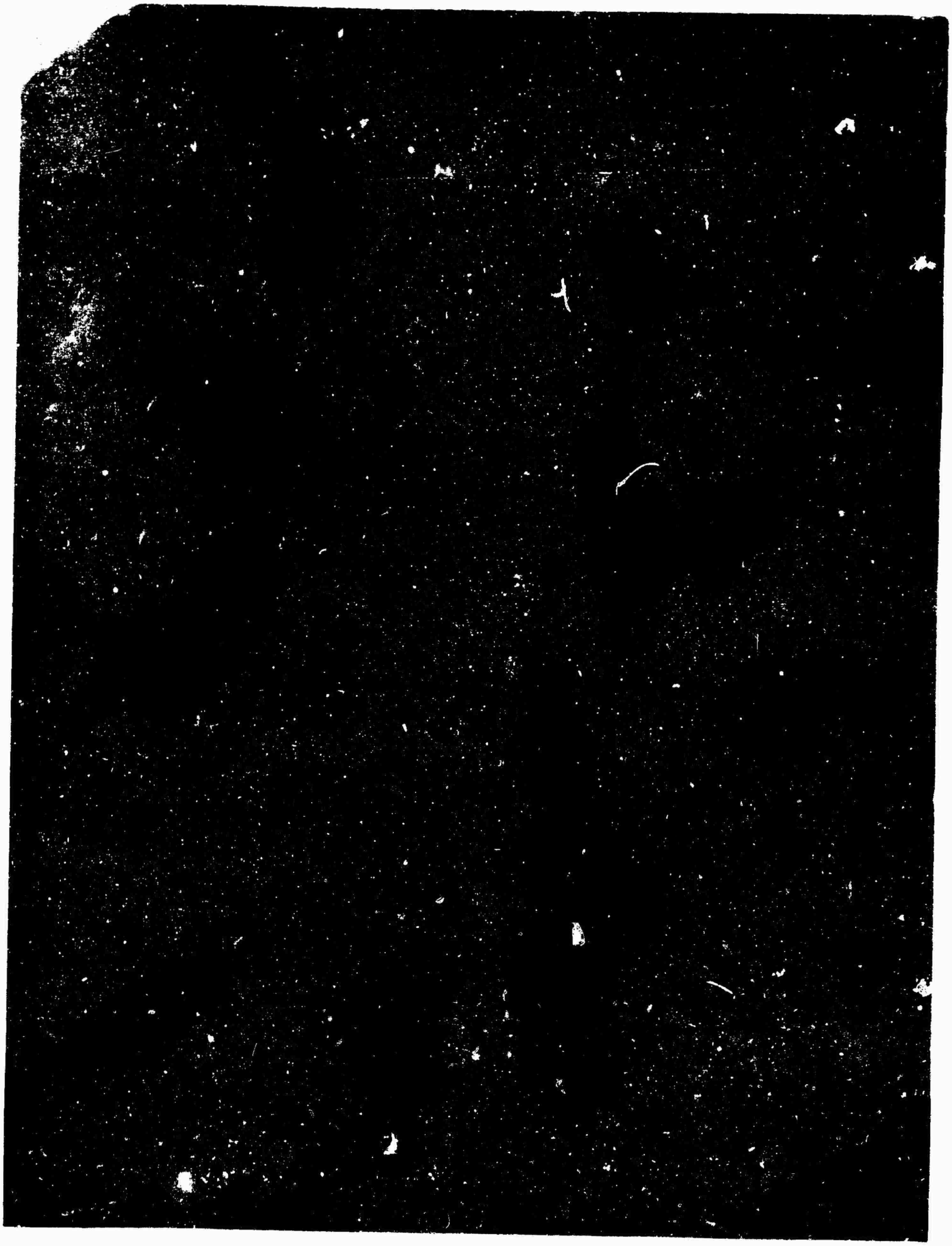

FIGURE 12

Sternal marrow cells of control cultures 12 days after preparation . May-grunwald stain. Magnification X 500.

FIGURE 13

Sternal marrow cells from flight cultures 12 days after prepa ation and 2 days after flight. May-grunwald stain. Magnification X 500.

FIGURE 14

Synovial cells of control cultures 12 days after preparation.
May-grunwald stain. Magnification X 500.

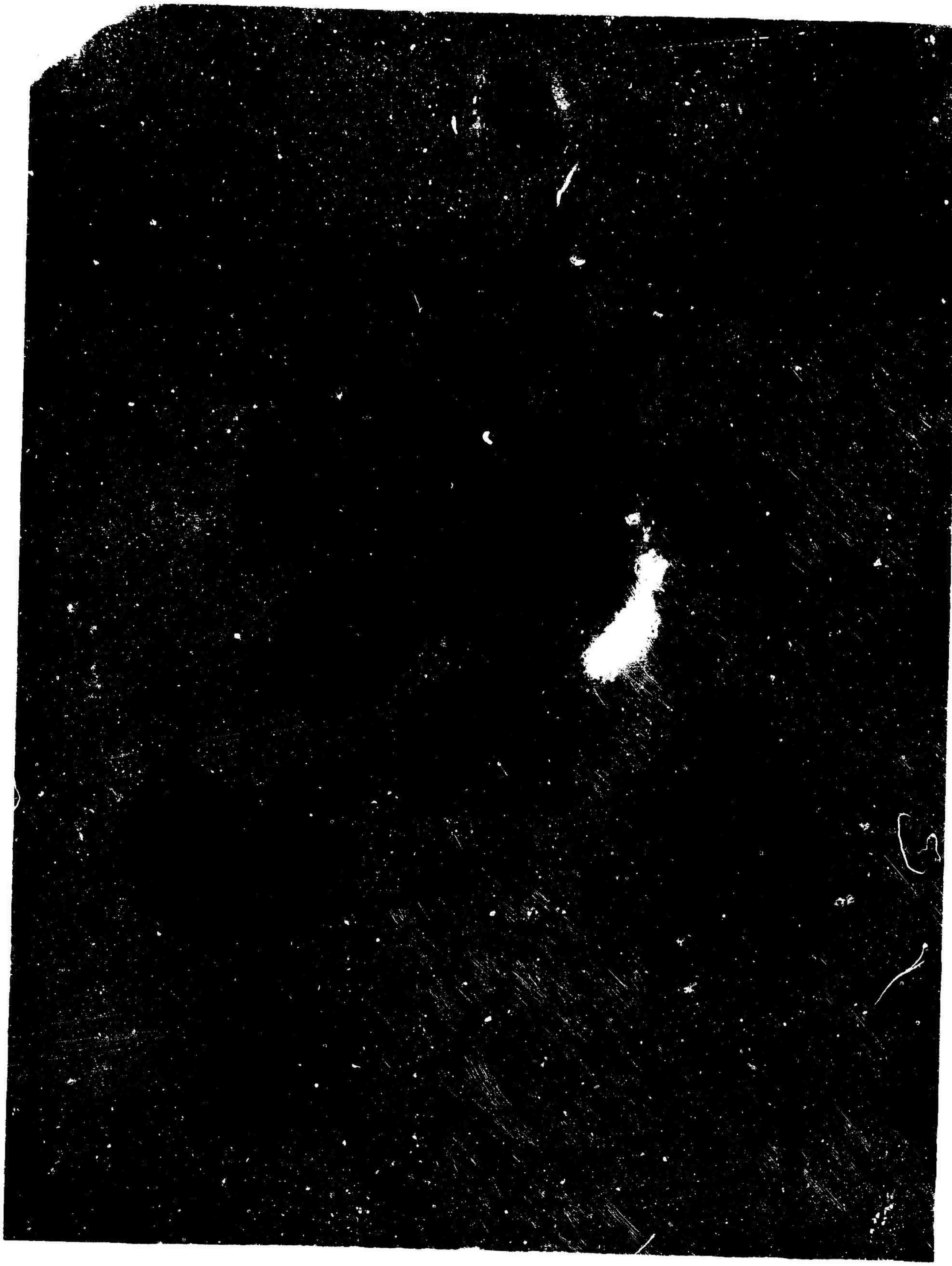

FIGURE 15

Synovial cells of flight cultures 12 days after preparation and 2 days after flight. May-grunwald stain. Magnification X 500.

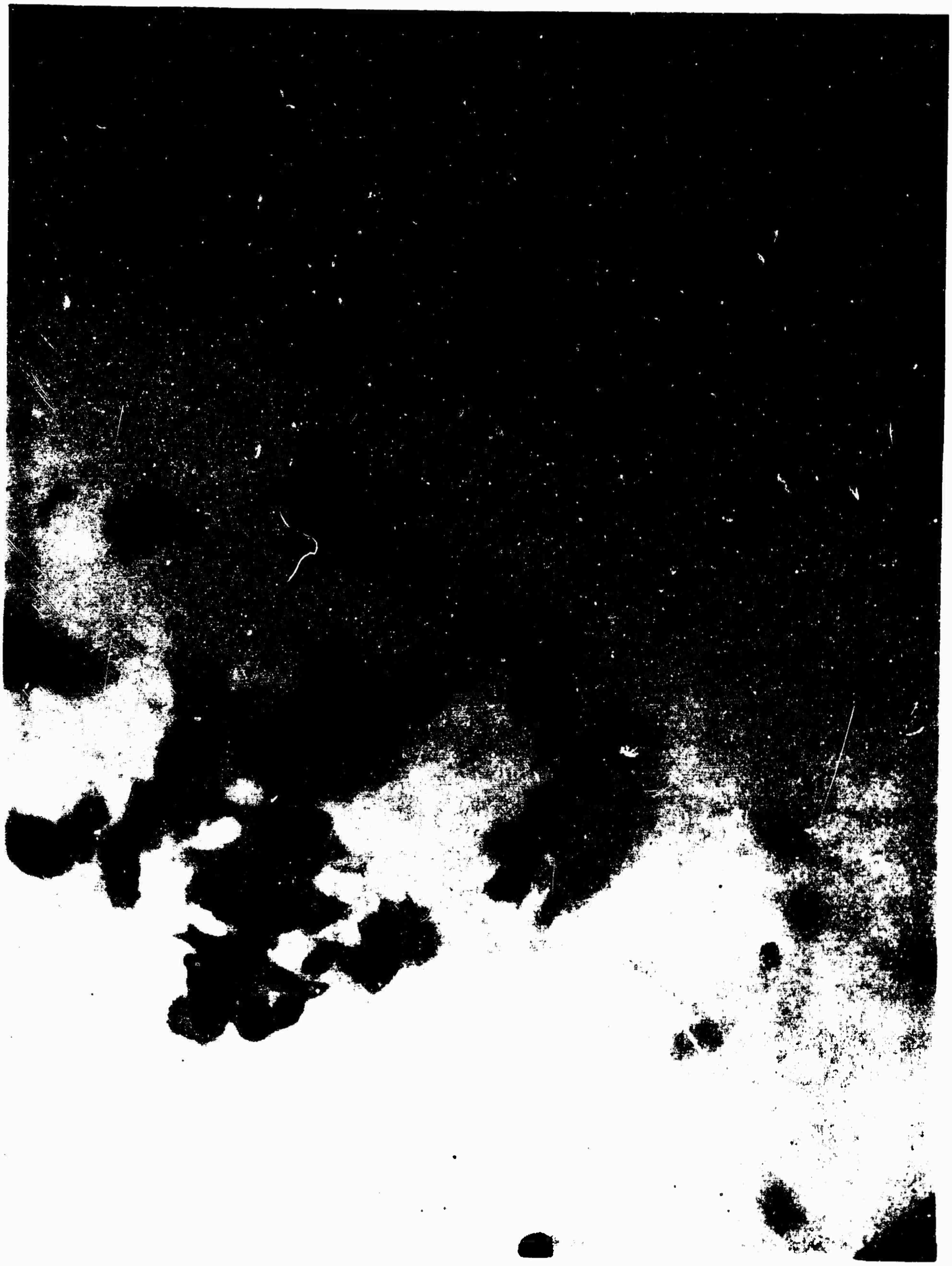

FIGURE 16

Hela cells of flight cultures 12 days after preparation and 2 days after flight. May-grunwald stai.. Magnification X 500.

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LECTURES IN AEROSPACE MEDICINE

RADIOBIOLOGICAL EXPERIMENTS IN DISCOVERER SATELLITES

IV. EXPERIMENTS WITH PHOTOSYNTHETIC ORGANISMS IN DISCOVERER VEHICLES


Presented By

J. N. Phillips, Jr., Ph.D.

Research Biologist

Space Ecology Branch

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RADIOBIOLOGICAL EXPERIMENTS IN DISCOVERER SATELLITES

IV. EXPERIMENTS WITH PHOTOSYNTHETIC ORGANISMS IN DISCOVERER VEHICLES

by

J. N. Phillips, Jr., Ph.D.

Man's foreseeable tenacy in space is dependent upon reliable life support systems to provide him with oxygen and food and to remove carbon dioxide and wastes. Inanimate, non-regenerative systems are currently capable of meeting these logistic requirements for at least 30 days. Eventually, however, the mission time must be extended past capabilities of non-regenerative life support systems in terms of weight and propulsion demands. Thus, among prime objectives of the space research program of the School of Aviation Medicine must be listed a search for reliable, self-regenerating life support systems with long time capabilities. Many compelling reasons have indicated that microorganism photosynthesis, such as is performed by unicellular green algae, can best provide regenerative biological management of life-support logistics for space travel.

One restrictive parameter imposed on such systems is that the organisms must be able to survive, photosynthesize and grow under the environmental conditions to which man will be exposed in space travel or habitation. Experiments have been devised, implemented and executed to learn if selected algal species can survive in space as a first step toward resolution of the above questions, as yet unanswered. The Discoverer vehicles offered a means of space environment exposure well suited to initial resolutions required.

NOTE: This manuscript reflects the views of the author and should not be considered official Air Force policy.

In these experiments, algal cells have been exposed to the space environment in a recoverable capsule. Recovered cells have been analyzed for viability, ability to grow, ability to photosynthesize and genetic stability. All experimental results have been compared with both ground controls and laboratory controls. Genetic analyses performed include visual and microscopic observations to detect any gross morphological changes, comparison of growth and photosynthetic rates with those of parent cultures and exhaustive auxanographic analysis to detect biochemical mutants.

Results to date clearly indicate that the algal cells are not detectably affected in any degenerative fashion by exposure to space environments. They have further exhibited very stable genetic characteristics and no detectable mutability. These results, while only preliminary, allow us to proceed with considerable confidence to the problems yet unsolved involving these systems. For example, experiments and apparatus are now being devised to allow us to measure in-flight growth and photosynthesis of these cells while they are being exposed to the weightlessness and radiations of the space environment. Our confidence in the validity of a biological management of life-support logistics increases with each experiment. We strongly believe that these experiments materially contribute to solutions of larger problems whose inevitable solutions will permit man's indefinite travel in and habitation of space environments, at least within our own solar system.

LECTURES IN AEROSPACE MEDICINE

DYNA-SOAR PILOT TRAINING

Presented By

Lieutenant Colonel Burt Rowen

Chief, Human Factors Branch

Air Force Flight Test Center

DYNA-SOAR PILOT TRAINING

by

Lieutenant Colonel Burt Rowen

The selection of DS-1 pilots requires a program for their familiarization and training in all the aspects of flight from the familiar supersonic regime to flight at hypersonic and orbital velocity. The requirements of the astronaut embarking in near space flight are many and varied, and have been discussed at length in general terms by many authors. The purpose of this program will be to present specific tasks, within present knowledge and known facilities, to satisfy the objective of preparing selected pilots to flight test the Dyna-Soar I.

To proceed in an orderly manner a category will be assigned each broad area pilots will investigate, or in which the pilots will be investigated. Detailed discussion of each category will offer the tasks the pilots will be expected to complete. In addition many factors necessary for training will involve knowledge and equipment not presently available. This will form a basis for a discussion of requirements to fulfill this and other space programs.

Selection: Selection is the obvious first category to examine. What kind of persons, who are they, and what is the criteria to be used in their selection? The aptitudes and skills involved require knowledges and understandings in: (a) proficiency and experience as pilots of high speed, high performance jet or rocket aircraft; (b) detailed engineering understanding of the operation and maintenance of the power plant, controls, and environment-conditioning equipment of the spacecraft;

(c) medical and physiologic training in human performance and functioning, with particular emphasis on survival and efficiency in the spacecraft; (d) detailed understanding of the operation and maintenance of all communications and scientific and military observational equipment; and (e) detailed understanding of the mission plan in relation to navigational and astronomical frames of reference.

Graduate test pilots have engineering and scientific training, interest and curiosity, and are very experienced in high performance aircraft. Therefore, the selection should logically be made from this group. To be more specific, pilots should be selected from among those of the Flight Test Operations Division, Air Force Flight Test Center, Edwards Air Force Base, California. The premise here is that these pilots have completed most of the basic screening and selection by (a) being accepted and completing the Test Pilot School; (b) being accepted for assignment in Flight Test Operations at Edwards AFB because of high standing in their school class; class standing determined by flying ability, scholastic achievement, and attitude; (c) experience in performance, stability, and control testing in new aircraft, this experience not being readily obtainable at any other Center of the ARDC. Equal excellence is expected from those NASA pilots to be selected by their organization.

Each pilot will be from among the type discussed and will have at least a Bachelor's degree in one of the Engineering Sciences. Several other factors such as height-weight relations and age are not within the province of this proposal to be exactly delineated and are left open.

Such factors are significant and must be resolved based on payload and cabin requirements, and clinical judgment.

In conclusion for this category two points must be stressed: (a) personnel must be selected immediately so they can be identified with the project from its present blueprint stage to flight test; and (b) selection must be considered a continuous process since the progress of the training program will provide for further selection and attrition.

Clinical Screening: The first phase of selecting DS-1 pilots should be their medical evaluation. This can be determined by screening at the USAF Aerospace Medical Center, Brooks AFB, Texas. This screening is similar to the medical examining program of the X-15 pilots and Mercury Astronauts. The results of the screening would be twofold: first to identify any physical deficiency that would give cause for elimination and second to become aware of minor discrepancies such as obesity, less-than-best current physical condition, etc. This will provide data to allow implementing a programmed and scheduled activity to maintain a high level of good physical condition. A program of physical training is recommended and can be handled adequately with existing facilities of the Air Force Flight Test Center.

Stress Testing: Psycho-physiological screening and stress testing has received mixed feeling of acceptance by experienced pilots when it is used to determine whether they are suited to fly very high performance aircraft. Some of these feelings are shared since the test pilot has proved his adaptability to new soul and mind disturbing situations. The test pilot performs with instrumentation recording every action,

he talks to contractors about their aircraft (and they are concerned about many hundreds of thousands of dollars) and every word he speaks is weighed for its accuracy, competance, and technical value. He has coped with aircraft responses and motion not previously predicted in analytic and wind tunnel studies. These factors ar others that a pilot routinely encounters in Flight Test Operations have added up to a clinical screening which in the past were used to help determine which persons were chosen for such projects as the X-series rocket aircraft. In addition to all this was the evidence of desire, the "want to do", which is absolutely essential for a project of radical departure such as DS-1. With highly experienced test pilots, it appears easier to determine a desire for radical departures in flight test programs. However, since some of the pilots chosen as candidates will receive their basic experience as test pilots (discussed in a later section) in the build-up to DS-1, it will be difficult to determine desire or motivation. For this reason, it is recommended that psycho-physiological screening and associated stress testing be made a category to which the DS-1 pilots must willingly submit prior to other specifics of a training program. Selected pilots should have no difficulty completing this process. Psychiatric and physiologic process will provide DS-1 pilots a keen insight into the aeromedical research efforts to define human requirements for space flight.

<u>Flight Test Program</u>: Flight test programs in the century series or other aircraft must be an essential part of training for DS-1. The problems of retainability, reassignment, and selection of new pilots

must allow these persons to conduct programs that include supersonic flight with an end result being recorded data in performance, stability and control, and written reports. Additional experience must be offered in qualitative stability and control to allow interpretation of aircraft stability and control systems that instrumented data cannot reveal. In this manner we guarantee the experienced test pilot for DS-1.

A projection of fighter aircraft programs for the next three years does not show sufficient promise to gain the greatest amount of flight training time. If this appears correct, it should be considered necessary to instrument a high performance aircraft to allow DS-1 pilots to gather and analyze flight test data. DS-1 pilots should also be provided the opportunity to cross-evaluate aircraft of the United States Navy and aircraft of special nature such as variable stability. Acquisition of a high performance variable stability and control aircraft will provide a valuable tool for DS-1 and other programs for stability and control, landing, and visibility problems.

Briefing on DS-1: A proper introduction would be a comprehensive briefing on the DS-1. This would be provided by various groups, Air Force, NASA and the Contractors, and would require several days since each subject would be presented in detail. Subject areas will include: (a) a general briefing to define the concept of DS-1; (b) the aerodynamic design and energy management; (c) vehicle secondary power and sub-system; (d) crew station and environment; (e) boosters; (f) range

(AMR & global), radar tracking, telemetry, and communications requirements; (g) flight test programs.

Preliminary Required Reading in Basic Rocket and Astronaut Theory: With a detailed briefing on DS-1 complete, many questions will be opened regarding the basic knowledge, the terms used, and their definitions. An immediate required reading program will be instituted to provide DS-1 pilots with the background to better evaluate and identify future tasks in the training program.

Detailed study will be required covering nozzle and thrust chamber theory and design, heat transfer, liquid and solid propellants, secondary power systems, guidance, tracking, communications, orbital flight paths, and possible military and scientific application for space vehicles.

Test Pilot School: A proposal must be offered to provide some formal courses in theory to provide DS-1 pilots with advanced knowledge in astronautics. It would be advisable to provide instruction that would apply directly to the program. As an example, a course should be offered on aerodynamics of lifting surfaces at hypersonic velocity near orbital altitudes. The subject matter should be presented using the contractor's design, his estimates of Cl max, L/D max, Cl optimum, their effects on orbital altitude and energy management, and boundary conditions due to turbulent or laminar flow, aero-dynamic heating, and dynamic pressure.

Other formal courses can be offered and are being planned by the USAF Test Pilot School where it is felt that the best talent and facilities are available for formal theoretical instruction.

TDY with Primary DS-1 Contractor: Initial training of DS-1 pilots will begin with a schedule of TDY assignments for two or three pilots for thirty-day periods at the contractor's facility. They will be assigned to and work with the DS-1 Engineering Design Group. This is considered essential for three reasons: (a) to be identified from the beginning to the contractor as DS-1 pilots; (b) obtain detailed information in all systems, such as cockpit, hydraulics, electric, secondary power, heat and vent, etc.; and (c) to provide influence and input in the design of these systems, particularly since USAF and NASA pilot experience will probably be greater than that of contractor pilots. It is probable there will be no contractor pilot participation, particularly for the launch operations at Cape Canaveral.

Continued TDY at the contractor's plant must be emphasized to maintain impetus and direction of this USAF guided flight test program.

Static Simulators: Static simulators have provided the tool for engineers and pilots to evaluate aircraft stability, control, control systems, displays, and aircraft and control responses. DS-1 pilots will be scheduled for static simulator practice for training and as necessary to evaluate controls and displays. In the past, it has been necessary to schedule this activity at the contractor's plant pending availability of the computer and pilot. The best arrangement to allow DS-1 pilots maximum utilization of static simulator training would be

to provide an analog computer in six degrees of freedom at the Air Force Flight Test Center. This additionally provides AFFTC engineers with a tool to do much needed flight research for the DS-1 and other supersonic and hypersonic aircraft programs. A properly equipped computer laboratory is considered essential and is recommended for early integration if the Air Force Flight Test Center is to offer training for future space activity.

Dynamic Simulation: Dynamic simulation in the form of centrifuge programs will be a scheduled activity as the DS-1 program progresses. As with the static simulator, the dynamic simulation will allow realistic evaluation of controls, stability, displays, and crew accommodations. At present only one facility exists that is adequate for closed-loop dynamic simulation - at Johnsville, Pa. This activity has a loaded schedule and is not easily available, is not convenient to the West Coast, and is not completely realistic since the infrequency of its availability leads pilots to do a program not wearing their full pressure suit, and the computer laboratory has old and dated equipment resulting in many delays during the conduct of a program, which generates some degree of pilot distrust. A national requirement exists for a "West Coast" dynamic simulator in support of the DS and other manned space programs. This centrifuge simulator should provide sophistication to allow flying in all "g" profiles, provide dynamic closed-loop simulation by tie-in to the computer laboratory previously recommended, and provide for the creation of and environment in the gondola, or one in which the gondola may be placed (i.e., artificial

atmosphere, visibility simulation, external cues, realistic personal equipment evaluation, etc.) to provide a realistic simulation of the space mission. This would provide a much needed facility for the best possible non-flight training of pilots for DS-1 and future space vehicles.

Land and Sea Survival Training: The booster flight test phase of DS-1 requires extensive operation over both land and oceans. Emergency recovery in other than a proposed landing area presents the pilot with the task of survival. Survival training on land will be offered DS-1 pilots at the AFFTC where a survival training course will begin prior to the end of 1960. Survival at sea will be provided and it is anticipated that coordination with the AF Air Rescue Service and the U. S. Navy will offer the best lessons in this subject.

Pressure Suit and Environment Training: Each pilot will acquire early in the program a full pressure suit, but its use must be more extensive than its mere consideration as a protective garment. These suits are in a continuing process of development and it is expected that DS-1 pilots will assist in their development while becoming used to wearing the garment for several hours and developing a tolerance for confinement, restricted visibility and mobility, uncomfortable variation of temperature and humidity, and change in internal suit pressures because of variation in cabin pressure. Much of the environment conditioning will be accomplished by scheduling in special chambers at the AFFTC. In addition, adaptation to these conditions while performing vital flight tasks are necessary and will be accomplished in

conjunction with centrifuge programs and in two-place aircraft in flight. It is recommended a two-place aircraft such as the TF-102 used to support the X-15 human factors program be considered a continued requirement to support the DS-1 program.

Astronautic Symposiums: With the science of astronautics in ascendancy, many professional societies such as the IAS, and American Rocket Society, hold symposiums presenting papers by distinguished men of the profession of aeronautics. Often these symposia are held in conjunction with the ARDC or Office of Scientific Research. The value of material presented in these instances increases markedly with the large number of classified sessions. It is intended DS-1 pilots will attend these meetings to accrue knowledge and current thinking in Astronautics, to lend prestige to themselves, the AFFTC, the ARDC and the USAF. The intent in this case is neither exploitation of the pilots as public figures nor of the program as such. Public relations concerning the program and the individuals involved must be conducted, it is recognized - but conservatively and sensibly, with due regard for the national interest in this venture and for the importance of the program in advancing space research.

Cape Canaveral and Atlantic Missile Range: The most significant portion of the flight test program will be conducted from Cape Canaveral to islands of the Atlantic Missile Range. A briefing tour and inspection of Cape Canaveral will be given to all DS-1 pilots. It is planned to have the tour co-incident with a launch operation so the preparation, countdown and launch of a Jupiter, Thor, Atlas, or Titan

may be observed. A knowledge of operation at the Cape is required as, for one example, DS-1 pilots must make or approve a decision on the method and division of responsibility between himself and the Range Safety Officer in the event of emergency on or shortly after leaving the launch pad. Pilots will be scheduled for additional visits during each unmanned DS-1 launch. The initial tour of the Cape will be followed by a flight along the islands of the AMR to visually learn the geography, the size, shape and particularly the planned and emergency recovery sites. Visual identification should be extremely significant since the pilot will have no external vision until after re-entry. In the event of loss of tracking and communication failure the pilot may have only visual means to identify position and selection of the intended recovery area. It is proposed that high altitude flights (35,000 to 45,000 feet) will be provided for training in identifying the islands along the Atlantic Missile Range.

<u>Projects X-15 and Mercury</u>: The X-15 program and the Mercury project will provide a great amount of information beneficial to DS-1. DS-1 pilots will be briefed on the X-15 program periodically at the AFFTC and will pilot chase aircraft on X-15 missions. This will provide a background on dead stick landing problems, air launch procedures, and knowledge of the X-15 High Range. Air launch, use of High Range, and dead stick landings are all elements of the initial DS-1 flight test program. Periodic briefings on Project Mercury will be arranged with the NASA so its progress and problems, where compatible with DS-1, will become useful knowledge.

Additional areas suggest themselves such as dead stick landing practice in aircraft configured to the visibility and L/D of the DS-1, and possible rocket flights. These are valid thoughts and may be firm requirements as the program progresses. Additional categories, not included in this proposal, will be suggested or become obvious with further thought and coordination. They can be accepted or rejected after careful evaluation. Care must be used to provide training subjects that will have direct benefit to the pilot preparing for the DS-1 program. As the number of pilots assigned to the DS program increases, areas of primary responsibility will be assigned. This system has proven successful in the Mercury project and it is anticipated as a guarantee of success in the DS program. The assignment of a test pilot early in the development program area of a new manned weapon system has always led to a practical, usable application of technological knowledge.

The foregoing has been presented as a guide to the ARDC position regarding training of test pilots for the Dyna-Soar program.

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LECTURES IN AEROSPACE MEDICINE

EXTENDED FUTURE MANNED SPACE OPERATIONS

Presented by

George P. Sutton

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Rocketdyne

A Division of North American Aviation, Inc.

# EXTENDED FUTURE MANNED SPACE OPERATIONS

by

George P. Sutton

Those of you at this meeting today as aero-medical people undoubtedly have an increasing awareness of the part you will be playing in the future operations of manned space systems. While future space flight operations will use both manned and unmanned vehicle systems, this discussion will be restricted to those systems of particular interest to you--manned satellites and space probes. As you all know, we are at the threshold of man's first adventure beyond the atmosphere and the exploration of the thin, vacuous environment of space. We are all thinking and planning for the more complicated and demanding manned space missions which will undoubtedly follow the early experiments. Our immediate problem is to determine that man can survive in space. In the first flights he will serve only as a test specimen. Thereafter we will see if he can function effectively as an observer and ultimately as an operator.

Before we can discuss future extended space operations, there are several assumptions that must be made. First, we must assume that man will be able to survive in space in spite of the hazards that we know exist and the hazards that as yet are unknown. This includes such

problems as radiation, meteorites, or the vacuum. Furthermore, we must assume that we will have, in due course, reliable space systems and effective and reliable booster vehicles. And we also assume here, that manned space flight will be preceded by exploration with unmanned vehicles which will help to define the environment and solve the many vague problems that exist in space ship design today.

At the outset I want to be careful to distinguish between exploratory or research flights and those used in space operations. Here I refer to a system that is developed and is used in a relatively routine fashion.

The future progression of extended space operations will proceed along several different yet related lines. I want to point out four different classes of manned space vehicles: (1) single-man experimental vehicles, (2) multiman vehicles, (3) space stations, and (4) vehicles for multiship expeditions. Artists sketches of these four types are shown in Figure 1. Table 1 lists some of the directions of progress of various characteristics of these four categories of future manned space flight operations. Soon we intend to send a man up in a simple non-maneuverable capsule which will expose man for the first time to extended space conditions. It has a simple re-entry capability with no mechanism to alter its course. The Dyna-Soar type vehicle has been described as the next major single-man test vehicle; it will be capable of undertaking some maneuvers and orbits of low altitude. This comprises the first

class of manned vehicles, those that are primarily exploratory in nature and are intended for low earth orbits or suborbital operations only. The next major class will be somewhat larger in size, probably with a crew of two men or more, and capable of staying up for longer durations, and will essentially be able to go to higher orbits. The Apollo-type vehicle is perhaps representative of the first of many vehicles in this class. It is quite possible that some of these vehicles will become operational in nature and this will be discussed later in more detail.

The third class of vehicles is first temporary, then semi-permanent, and eventually permanent space stations. The first will be operated in near earth orbits and later versions in further orbits and perhaps as Lunar space stations. These of course will be important in future extended space operations.

The final class of vehicles that I wish to discuss are those of interplanetary exploration and operation. Here we are no longer talking about a single vehicle but a squadron of several vehicles which will go together to explore parts of our universe.

Let me now briefly discuss some of the various characteristics of the manned space vehicles as they apply to each of these progressively more difficult missions in these four categories.

The flight duration will increase with each class of vehicles as shown in Table 1. The <u>takeoff weight</u> and the <u>final vehicle stage payload</u>

will become increasingly larger as the mission difficulty increases and as the time schedule increases. The Class 2 type vehicle can be operational in the late 60's, the Class 3 and 4 types probably will not be operational until the 1970 period. Experimental vehicles will fly at earlier dates. It is possible that some limited short duration operations can be performed with a one-man vehicle in the mid sixties. This schedule is based on the assumption that the Saturn vehicle will not be developed until 1965 and that a larger vehicle will only be available around 1970.

With each class of manned space vehicle, the difficulty of the mission will increase. For example, the guidance requirements will become more complex; re-entry accuracy and heating problems will become more serious; and the maneuvering and attitude requirements will become more stringent.

The concept of modular design will become very prevalent with the later types of flight operations and may be tried in a simplified manner in the second class of vehicles. A modular design really means the use of relatively common structural parts that can be assembled in different manners to give different types of vehicle functions. For example, in the Apollo design, it is possible to have a final-stage manned vehicle which contains all the essentials for survival of man, re-entry, and flight control. Attached thereto are separate modules

for propulsion during orbital maneuvers, a separate module for life support equipment for extended orbit durations, and perhaps several other modules, each with a different function. When re-entry is desired, these other modules are dropped off in orbit and only the final-stage vehicle which is designed for re-entry is permitted to return to earth.

Increasing complexity applies also to the crew engineering and life support systems. For example, artificial gravity for the crew is a nice thing to have but in the minds of some experts it is not essential, particularly if the duration in orbit is only in the order of weeks. Thus, the early manned satellites will not have this luxury because it is expensive and complicated, but the later versions with long flight durations probably will have some means of artificial gravity inducement.

Systems for environment control, cabin interiors for example, must be provided under all circumstances. Backup systems such as climate control are more essential for the longer duration missions where escape or return to the earth is not readily possible.

Table 2 shows other characteristics of future manned space operations. In the early versions, the supply of food can be accomplished by storing food in containers. Some means of regenerating the food supply through a closed ecological system will be required in the later more advanced missions in the Class 4. Disposal of carbon dioxide and waste liquid products again becomes a more complicated system as flight durations

increase. For short-duration versions chemical sources of power seem to be adequate. But for the longer duration journeys with the higher power requirements associated with larger payloads, the nuclear reactor power source seems at this time to be the only means for accomplishing this type of mission. The development of a one megawatt nuclear reactor together with a heat rejection system is therefore essential for space stations and extensive interplanetary operations. All manned space systems require an attitude control system capable of orienting the space ships toward the earth, toward the sun, for proper communication antennae orientation, for proper solar energy capture, or for proper manned observations. In addition, manned satellites must have in their later version an onboard orbit control system for controlling orbital heights, speed, orbit orientation, and period of revolution. In the current systems it is probably contemplated to have this control function on the ground, but the future systems must definitely have this control function in the ship.

True long-duration space operations will require 24-hour operation. This makes it necessary for three or more men in a space ship. For some short-orbit missions it is conceivable that one or two men can perform such temporary space operations as servicing a satellite in orbit or short-duration reconnaissance.

You can see from Table 1 that future space operations are becoming increasingly more expensive for each mission. Our ability as a nation

to afford expensive projects must therefore be balanced against the benefits and the frequency with which we attempt such missions. It is certain that we will all become more selective in the types of missions that we will allow and we must try to pick only those objectives which we consider to be truly worthwhile.

## PURPOSE AND UTILITY OF MANNED SPACE OPERATION

I need not elaborate greatly on this topic because it has been the subject of much discussion and many speeches, but basically there are four principal purposes:

1. The engineering and testing of materials, components, and sub-systems necessary for the development of future, more difficult space systems.
2. Research in space medicine, biology, physics, astronomy, and many other areas of science which includes the investigation of other planets and the moon.
3. The military applications involve reconnaissance, surveillance, active defense, offense, and finally, command and control from a space observation post.
4. The commercial exploitation of the space environment for communications, meteorology, or navigation.

It is very likely that the scientific, commercial, and military applications will overlap in many areas and will possibly use many of the same subsystems with the same or very similar operating bases. As you know we are currently planning or developing systems in all of these areas. The very first truly operational system that will be used will likely be unmanned and will probably be the Navy's navigation system. It is very simple, does not require attitude stabilization, and could possibly be ready for operation next year.

These functions will all use unmanned satellite systems for some time to come. Only for advanced versions of lunar and planetary explorations, and for some engineering and military applications will we use a manned system. Present needs in commercial satellite applications call for only unmanned systems.

## MISSIONS FOR MEN IN SPACE

Let me discuss three types of basic missions for manned space vehicles. They are: space exploration, space bases, and space systems operations.

### Space Exploration

Once we have demonstrated the ability of men to survive in space we will use men as a functional subsystem in a complicated space system to explore the universe. After the first explorations of space near the

earth (that is, satellite type exploratory trips), we will attempt various lunar explorations, and finally, a planetary exploration. These will be relatively short-duration expeditions and the vehicles in the second category will probably be more than adequate for the first few flights. We will use man primarily as an observer to operate scientific instruments and to perhaps make occasional minor adjustments and repairs.

Space Bases

Our first attempt of a manned space base probably will not be made until 1968 or 1970, and again will be performed in near-earth space. It will serve as a space platform close to earth which can be useful for scientific, engineering, test, and military purposes.

First we will attempt to build a temporary base to be used for short periods of time. Later we will make it more permanent and eventually develop a fully permanent base. Here we must create an environment where a man can live and perform useful operations for some period of time; where he can exist in a sealed structure: where he can perform some effective operations in space such as assembly, maintenance, and servicing; and where he can overcome many of the psychological and physiological problems that you here have foreseen and discussed at many of your meetings. Today we cannot say very much about lunar bases or planetary bases. They will come considerably later, and they will be an order of

magnitude more complex. They will also require bigger vehicles and have more difficult mission objectives. The lunar base, for example, will require our ability to operate in an essentially foreign and hostile environment without atmosphere and perform various kinds of construction activities which are quite common here on earth. For example, we will have to learn how to make trenches and backfills, how to transport soil, how to accomplish blasting, how to join various pieces of modular construction on the moon (that is, welding, cutting, and joining of metals), how to build tunnels, how to build robots for construction, how to control the atmosphere inside a base, how to achieve thermal balance, how to supply water, food, and eliminate waste products, and how to overcome many other problems. There still are many open questions about lunar bases, for example, should we have one on the moon's surface or beneath the surface. Later when we talk about planetary bases we must contend with the hostile atmospheres, the difficulties of electronic communications through strange atmospheres, and the problems connected with capturing solar energy at a different place in our solar system. When we have permanent bases we can start thinking about colonizing them and it will be at that time that we will ask women to go alone into space. The social problem associated with mixed crews, and with the colonizing of these bases have, to the best of my knowledge, not been discussed at a meeting such as this, but we have plenty of time to think about it.

An essential part of any space base is its supply system. We need to bring replacement parts, expendable supplies, new equipment, new modules, and we need to return crew, data, and samples back to earth. The ferry vehicle system is an integral and necessary part of the over-all system. The ferry system can, one of these days, become economically self supporting. The exact economics of the ferry vehicles will depend on the payload size, the frequency of operating supply missions, the type of orbit to be considered, the techniques for recovering the various stages of the ferry boosters, the type and the method of operation of the launch base, the maintenance and repair schedule, and, of course, the reliability of its various subsystems. It is quite possible that eventually this will become a profitable item for a transportation company.

## SPACE SYSTEMS OPERATIONS

Let us examine several typical operations in space where a man can be usefully engaged as an integral part of a complex man-machine system. Briefly let us examine four basic operations: refueling, maintenance and servicing, rescue and return, and finally assembly operations.

### Refueling

Let me distinguish between several types of refueling operations. The first type is one where fuel is transferred from one vehicle to another. This permits the takeoff with a relatively small vehicle, but requires

many trips since small vehicles can carry only a limited payload. Because of the larger number of trips the individual vehicle can quite likely be cheaper and probably more reliable than a system using fewer large vehicles without refuelings. However, it is necessary to develop a rendezvous capability and refueling equipment for transferring fuel from one vehicle to another. This rendezvous maneuver may cost extra energy and certainly requires additional equipment which must yet be developed and tested. Although the vehicle cost for the smaller vehicle may be less than that of a larger vehicle which does require refueling, it is not obvious at this time as to which of the systems (one with refueling and one without refueling) will in the long run be cheaper and more desirable. It is very likely that the automatic rendezvousing technique and probably the unmanned automatic fuel transfer technique may be developed prior to attempting this with a manned refueling operation.

The initial applications for such refueling probably will be for recharging propellant into orbiting maneuvering satellite vehicles. This would permit the satellite vehicles to extend their maneuvering period and capability. Thereafter will probably follow the refueling of vehicles which have an interplanetary expedition capability.

It is likely that lunar expeditions will be accomplished without refueling, directly from the earth, and thus will not need this technique.

When the cost of the development of a set of small vehicles (which can refuel each other in orbit) together with their production cost is lower than the cost of developing and operating larger vehicles (with more stages and no need for refueling in space) then we will use refueling for space operations. After making a series of somewhat arbitrary and limiting assumptions, one can arrive at relations that crudely describe these cost relationships. The estimated effort or relative cost can be shown to be a function of payload as described in Figure 2. For small payloads it does not pay to refuel. To the best of my knowledge, no accurate study of refueling problems has yet been made.

The second type of refueling operations is that which utilizes available resources for generating fuel. Some of you have heard discussions of the possibility of using lunar material for generating oxygen and of the possibility of scooping oxygen out of the upper regions of the atmosphere for collection in the vehicle. Both of these schemes for using available materials and converting them into suitable propellants take energy which should, however, be readily available when nuclear reactors are perfected to the point where they can properly be installed in space vehicles. The possibility of evaporating stored liquid hydrogen for condensing the air as you go through the outer regions of the atmosphere has also been suggested as a possible mechanism for collecting propellant.

Maintenance and Servicing

Maintenance and servicing operations in space are one of the more significant operating contributions that a man can add to a complicated system. As you know, it is difficult enough to do maintenance and servicing in a shop here on earth without complicating such operations with the difficulties inherent in the space environment. It is therefore likely that initial operations for maintenance and servicing in space will be limited to very simple operations which require a minimum of additional tooling, checkout equipment, and supplies.

Let us go through a typical sequence which is necessary for a man to properly maintain, service, and repair defective equipment, whether it be space vehicles or any other complex system. Let us do this with the aid of Figure 3. First a man has to know that something is wrong with the vehicle system. This detection can be done by automatic warning devices, it can be done by monitoring the system operations through observation by men, or it can be done by exhausting a necessary supply, such as propellant, film, or batteries in the vehicle. It is next necessary to make a decision to identify the problem and to come up with a proper diagnosis of the trouble. With complicated systems the diagnosis of the trouble is not always a simple problem. It may require some fairly complicated measurements, it may require the operation of standby emergency systems, the use of particular tools and measuring instruments

to identify the trouble, it may involve the installation and use of very special test equipment, and of alternate methods of checkout to be sure of the diagnosis. It requires the determination of primary and secondary causes of the failure and the effects on other subsystems. It is a foregone conclusion that it is not possible to diagnose all the troubles that can beset a space ship, and maintenance and repair can, therefore, only be effective for a relatively small portion of the systems that are in a space ship. Let me repeat this, only a small portion of the many complex systems in a space ship lend themselves to maintenance, service and repair diagnosis in space.

Even if we had properly diagnosed the trouble and wished to take some corrective action, we may not be able to do so because of the lack of available spare parts, the lack of suitable test of assembly equipment and tools, or the lack of proper adjustment and calibration equipment. But let us assume that we have properly diagnosed the trouble and have decided to take some corrective action. It could either be the simple adjustment of a subsystem or a component, replacement of a component, replacement of a subsystem, a replacement of a complete system, the use of an alternate subsystem after shutting down the troubled subsystem, or a combination of any of the above. Once we have taken this corrective action, we still need to check, calibrate, and test the corrected system to determine that it is functioning properly, and only

then can we put the system back into operation. This applies equally well to fluid-driven alternator for electric current, to navigation equipment, or to communications equipment. It is essentially impossible to carry a full complement of spare parts; therefore, only certain critical components can actually be replaced.

So you see, before we will ever attempt manned servicing and maintenance operation, we are already laboring under the difficulty that only certain selective failures can be corrected in space flight. The concept of maintenance by man requires really a brand new design philosophy, namely, all parts that need servicing and maintenance have to be put into very accessible places, with very simple connections and interfaces, and built-in diagnostic devices that make it readily possible to tell the exact nature of a failure or a servicing requirement. In some cases, it will even be possible to build the diagnostic tools and the corrective tools and devices directly into the system so that all man needs to do is switch to an alternate mode of operation for a given subsystem.

In several prior papers it was stated that manned maintenance will have a better chance if it is possible to send a manned repair vehicle into orbit for servicing, repairing, and maintaining other unmanned vehicles or possibly even for recovering special payloads. Let us examine more closely the concept of a special manned service vehicle - the space equivalent of the repairman who comes to your home with his truck.

This manned service vehicle, then, is a subsystem in a complex manned machine space vehicle system. Such a manned satellite repair system will pay if the cost of the manned service vehicle flights, plus the cost of replacing those payloads in orbit that cannot be fixed or repaired in space, is less than the cost of replacing the satellite vehicles that would have failed in orbit without manned maintenance. I have a number of calculations under the assumptions listed in the appendix.

The conclusions that can be drawn from this study are really fairly obvious and can be stated roughly as follows. It pays to have a manned service vehicle if the proportion of fixes that can be accomplished by man relative to the total possible failures is relatively large and if the number of vehicles to be serviced in orbit is relatively large. It also pays to have such a manned service system when the reliability of the system to be serviced in orbit is relatively poor and will fail often. The chances for this concept to be economical are good, if the manned service vehicle has a maneuvering capability and is able to service a maximum of orbiting satellites in one manned service vehicle flight trip.

By looking at Figures 4 and 5 you can see these conclusions in more vivid form.

Rescue and Recovery

The rescue problems differ in the various phases of space flight. Near the launch point on Earth or during the early assent to orbit, it is possible to escape with an escape rocket capsule similar to that used on Project Mercury. This is a feasible system for quickly ejecting a man from what might potentially be a very energetic conflagration. During an earth orbit, a failure of a space ship will permit the actuation of a retrorocket which in turn will initiate the landing of a capsule or terminal vehicle on earth. It will take some time (probably between 10 and 50 minutes) to recover a manned capsule from orbit and therefore this escape maneuver is a good solution only for emergencies which do not require a quick immediate return to earth. A malfunction of a communication system or a food supply system would perhaps not require a quick turn to earth yet would not make it desirable to maintain in orbit. However, an impact with a meteorite or a high solar activity with its associated radiation does not lend itself readily to a quick rescue or escape solution.

During an orbit or a traverse of true space, such as there is in a truly interplanetary maneuver or a lunar journey, there does not seem to be a nice lightweight method for getting a man back to earth except by the use of a vehicle which is essentially similar and equally heavy to the one that may fail. Therefore, an immediate easy escape mechanism or

rescue mechanism is not a simple solution. It seems, therefore, that the flight by a squadron of vehicles in close contact is today the only possible hope for increasing the safety of the occupants of one of the vehicles. However, this requires the strenuous process of transferring men from one ship to another, and this in itself, has many problems which yet need to be solved.

During the re-entry procedure, the escape and rescue problem is again a difficult one during some of the phases of re-entry operation. During the high heating portions of re-entry, and the high deceleration portions, an escape or rescue does not seem to be easily feasible without an enormous additional complication and weight penalty. The man's goose is literally cooked during this portion of the flight. During the other portions of the re-entry flight, particularly those at low altitude, a rescue operation is again possible at relatively little excess weight.

In many rescue and escape operations, the extra complication for permitting a "safe" escape may be too excessive or too heavy to make it feasible and it will probably be necessary to design very often not to rescue a man in a space vehicle, in a specific flight path and failure situation. It will be impossible to design, really, for every mode of failure during every portion of the flight, and we will concentrate on providing escape means during those portions which we deem to be most critical and, for which we know how to design. The time element of a

given failure is very significant. If the man needs immediate relief, such as the failure of a booster during launching, then the problem is very different from the situation where there is time available for rescue and escape. If, for instance, there is a malfunction of the navigation system or a small leak in the pressurized cabin, then there is time to attempt not only some corrective action, but also, to attempt an elaborate escape maneuver. If there is sufficient time before the failure becomes critical to the man, then one can even consider the rescue vehicle concept, namely, the sending of an "ambulance" or "repair ship" after the distressed space vehicle and transfer the occupants that are in danger to the rescue vehicle and return to earth.

Assembly in Orbit

We do not know today that we can risk the prolonged exposure of a man protected only by a space suit against the environments of outer space. Initial assembly operations will therefore be conducted very likely from the relatively safe perch of a space cabin of one of the space vehicles. The concept of having a small astronautical tug is an interesting one whereby man, inside a small vehicle with limited maneuvering capability, is able to perform certain simple jobs, assembly operations, and supply missions that are easily accessible to him and in close proximity to his large base vehicle. It will be necessary to design the vehicles that

are to be assembled in space in such a manner that the actual fitting, and assembly, and checkout operations are indeed very straightforward and simple and do not require complicated operations by man. Another concept of achieving initial orbit assemblies is to have a radio controlled robot with TV and remote control tools.

This robot is then operated from a space ship cabin by man and thus will perform the assembly operations remotely. The radius of action here, too, is limited to a relatively short duration and range. As with the astronautical tug, the controlled robot is limited in its flexibility and reliability. Finally, we will learn how man himself can operate in space, protected in a suitable manner to do the job himself without automatic tools. This will require, basically, a mother ship from which the man can transfer through a pressure lock to the outer space environment and which permits him to operate from a base just as a tender ship operates with its submarines. Again, as in the maintenance and repair missions, the newly assembled space ship needs to be checked out, calibrated, pressure tested and functionally prepared before actual use. Again this requires special tools, techniques and assembly procedures, which as yet need to be developed.

With the complications of the space environment to be encountered, it is probably safe to predict that we will minimize the manned space assembly operations as long and as much as possible in order to limit the number of operations and type of assembly gear that has to be carried in space.

ECONOMICS OF SPACE OPERATION

I have already indicated that future extended space operations, particularly manned space operations, will be exceedingly expensive. I furthermore postulated that we will learn about the technical problems by prior flights, both manned and unmanned, and that we will somehow learn to make reliable boosters available to us. As you know, the Saturn will permit flights of the Apollo type and similar short-duration near space missions, but we will need a bigger booster beyond that for the third and fourth category missions that I have mentioned. Before true manned space operations can really be achieved, such a bigger multistage booster will be a necessity and will have to be made available. This in itself is a major expenditure and will probably cost at least two and probably four billion dollars for satisfactory development. Estimated operating costs are also high and are listed in Table 1. These big vehicles can be capable of carrying payloads larger than a hundred thousand pounds into far Earth orbits and space probe trajectories. Such vehicles will have a thrust at takeoff in excess of five million pounds.

While at this time in world history, space explorations and future space operations have the motivation of increasing national prestige, scientific advancement, and the promotion of general world science, these will eventually come down to the common denominator of pure

economics. The method that will give the largest return for the least investment will be the one chosen for routine space operations. The dollars that will be available for this endeavor will probably be somewhat limited and manned space operations will have to compete for the available money just as much as other worthy national and international goals.

## CONCLUSION

The inclusion of man in a given space operating system, eventually will depend on a basic concept of proving that the presence of man in space is economically beneficial. That is, the system reliability must be improved or the flexibility of the mission must be sufficiently enhanced to make alternate ways of doing this mission without man considerably more expensive. I have presented to you a specific set of analyses in my paper in which I examined specifically the economics of using man for maintenance, servicing, and repair missions and I have arrived at the conclusion that man is economically desirable for some of these missions under certain severely restricted conditions and assumptions. To put it another way, it appears to me that it will pay us to put a man into orbit only for certain specific missions and operations. For others, man will turn out to be economically unfeasible and in the long run will not be used. We do as yet not know enough about the many assumptions we must

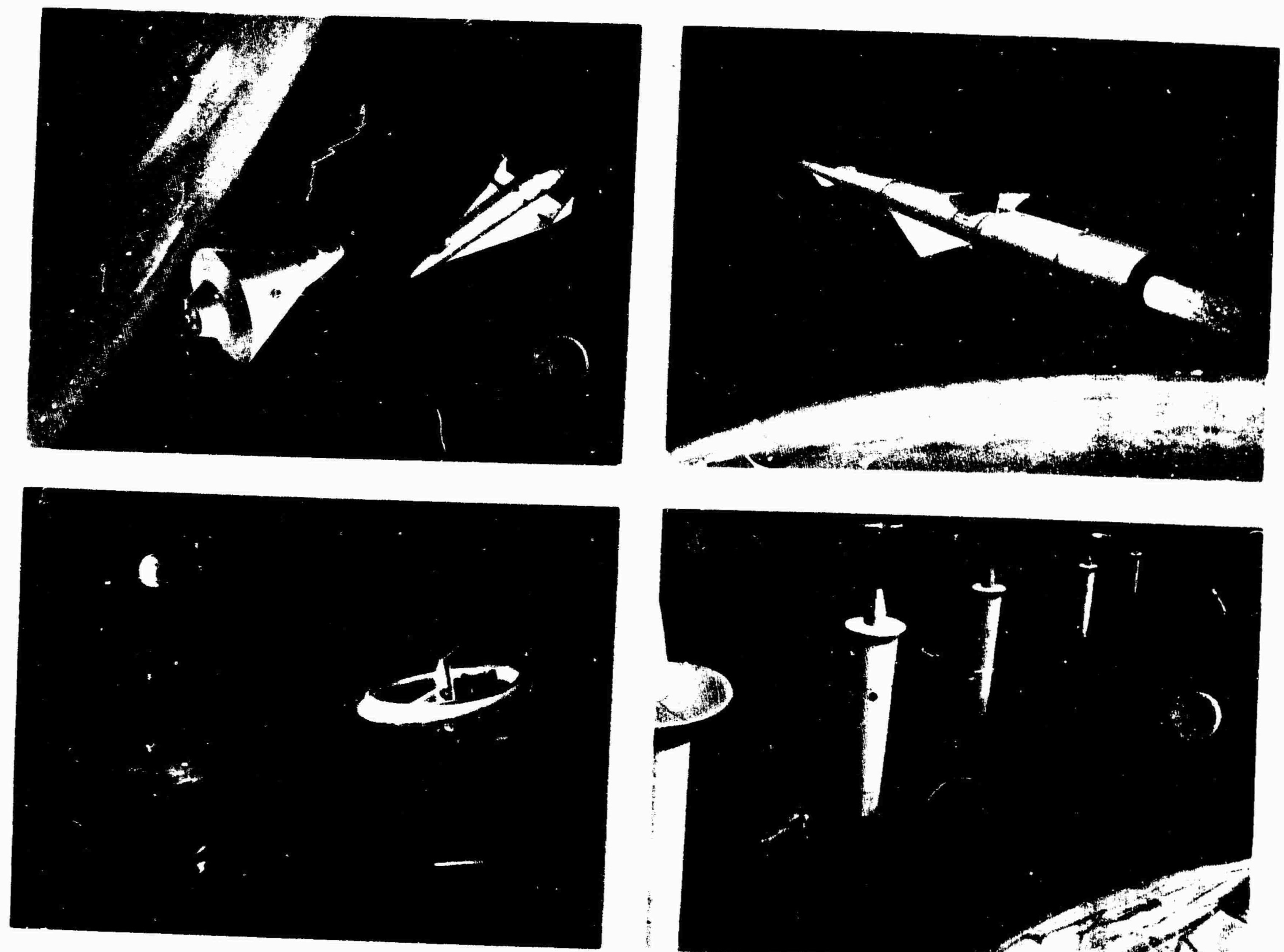
make to closely define the area in which it will pay us to use man as an integral part of an operating space system. My own personal feeling is that the number of missions that man will conduct as an operator will be relatively very few for the next 15 years.

I want to state again that it is too early to make a definite conclusion about extended future manned space operations. We must wait until the current limitations on the state of the art have been extended by intensive research and development on many related fields of technology and space systems. Several things, however, appear fairly safe conclusions. For extended future manned space operations we do need a new big booster so that we will have the ability to carry the necessary payloads for long-duration, long-distance manned missions. Further, we will need a lightweight nuclear reactor type power source which is shielded for manned space operation. We will need experience in sustaining a man in the hostile environment of space. We will need a good microwave, long-distance communications system. We will furthermore need to know the results of many of the other programs that are now going on.

It has been pointed out by previous speakers here that we are sadly lacking in technical and medical information and that we have yet much to learn before we can proceed with extended manned space operations. However, with each satellite and space probe that we send up, we are advancing

our fund of knowledge and are thus acquiring additional information to solve the many technical and non-technical problems that must be overcome before an extensive manned system can be put into operation.

There is no question in my mind that we will use a man for exploratory space flight missions to learn more about space, its environments, and usefulness. We will accomplish the first such feat soon and many more exploratory flights thereafter. But the routine use of man as a sub-system in complex extended future space operating systems is uncertain today.



1. Mercury & Dyna-Soar are Typical of Early Manned Exploratory Vehicles
2. Operation for Several Days, Higher Orbits, Greater Payloads in Late 60's
3. Artist's Concept of Space Station
4. Artist's Concept of Interplanetary Expedition

Figure 1.

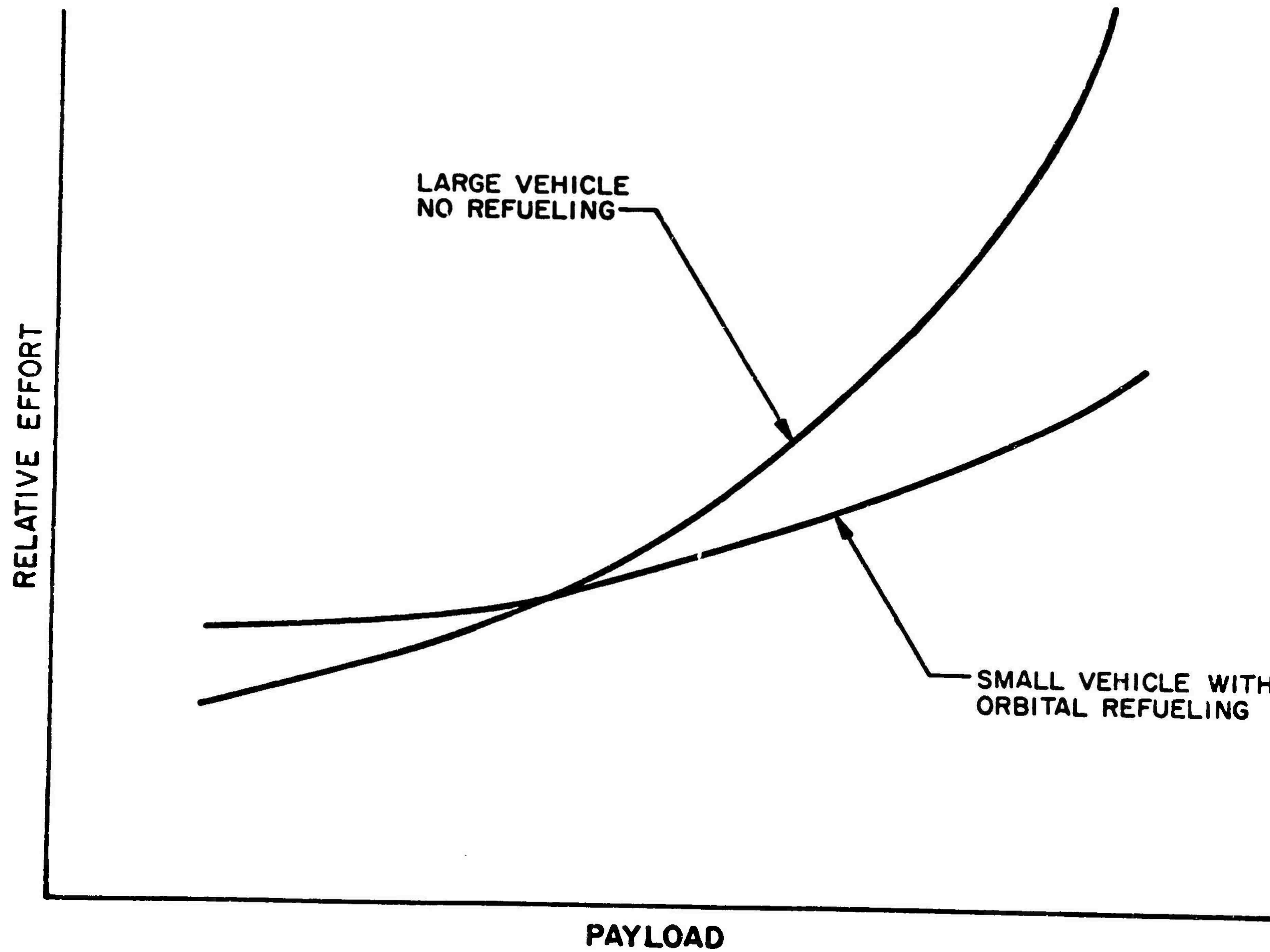



Figure 2. Refueling in Space

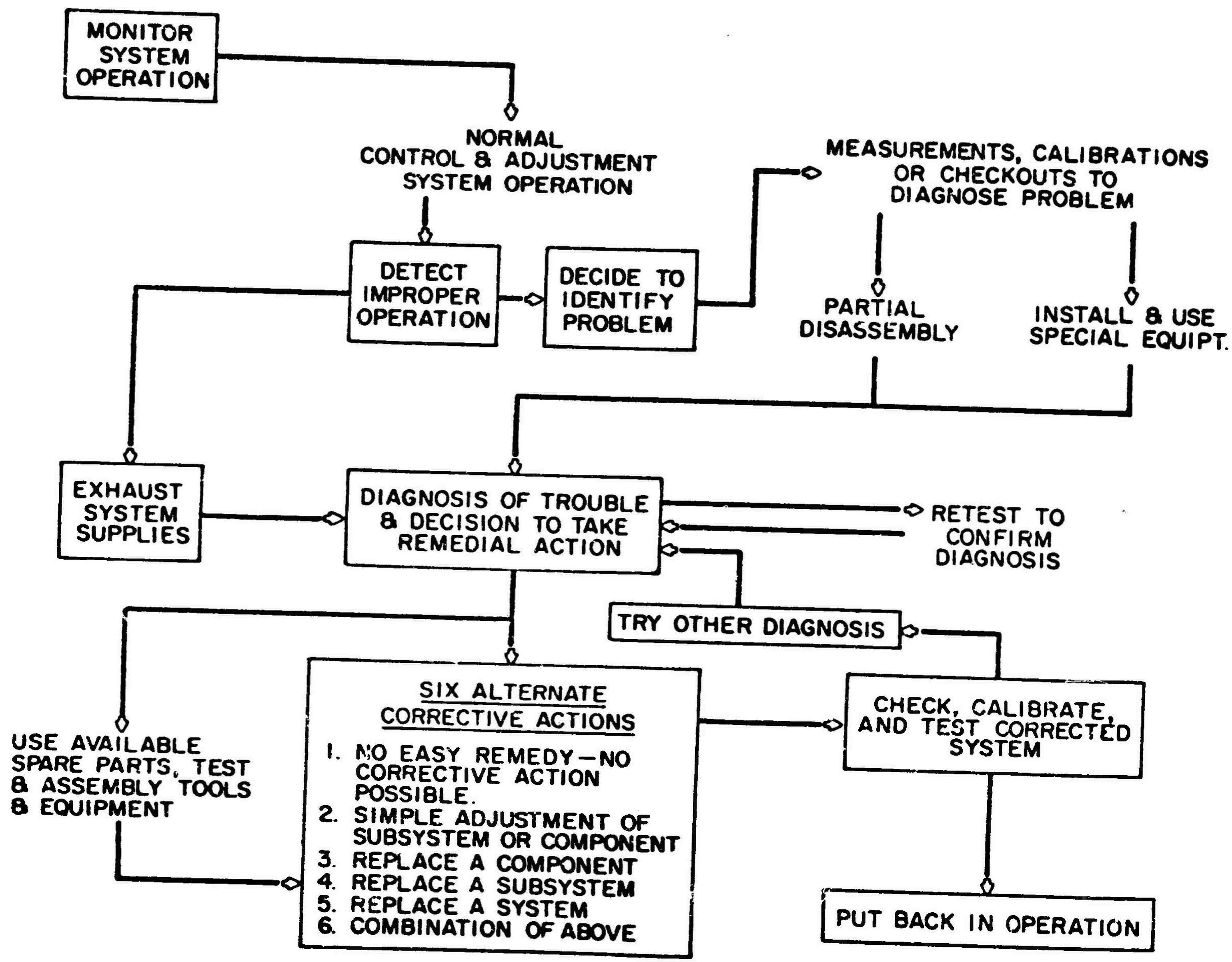



Figure 3. Diagram of Maintenance and Service or Repair Operation

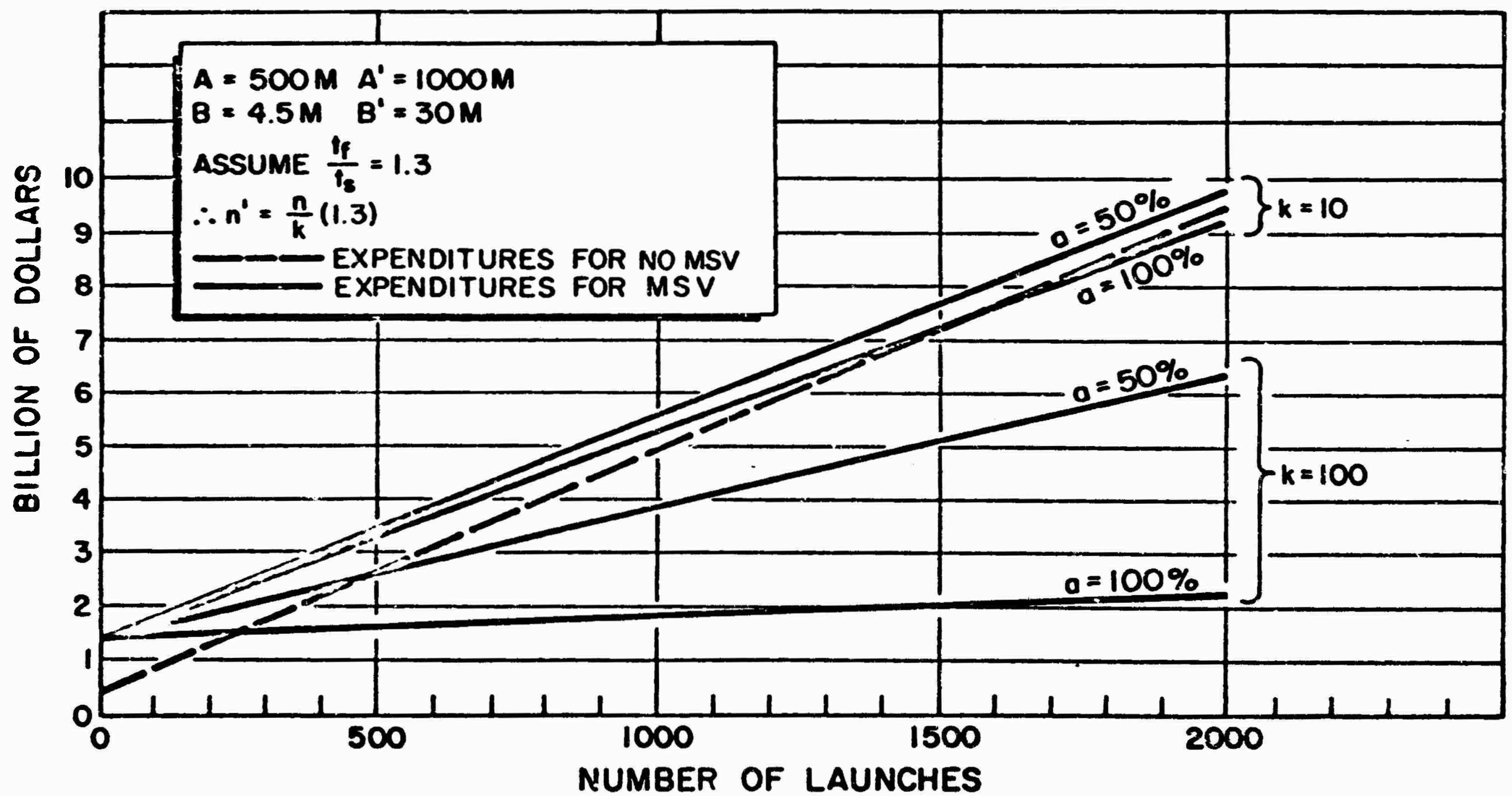



Figure 4. Total Costs of Manned Maintenance Vehicle vs Numb. of Launches

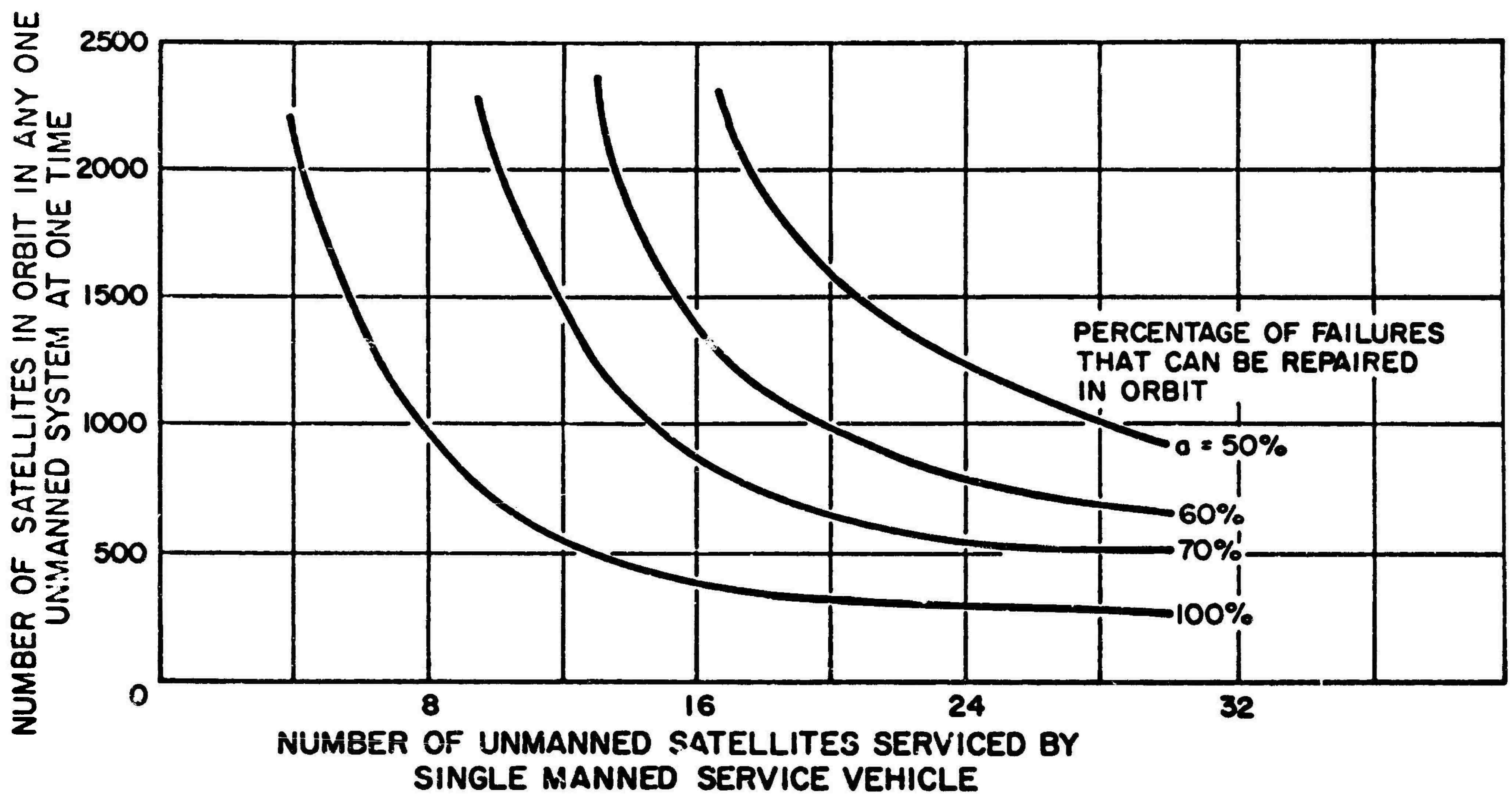



Figure 5. Manned Service Vehicle Capabilities

TABLE 1

CHARACTERISTICS OF FUTURE MANNED SPACE FLIGHT OPERATIONS

| Mission Type | Low Earth Orbits; Suborbital (MERCURY, DYNASOAR I) | Higher Earth Orbits and exploration (APOLLO) | Near Earth and Lunar Space Stations and Operation | Interplanetary Exploration and Operation (Multi-vehicle squadron) |
|---|---|---|---|---|
| Take-off Weight (1000 lb) | 200 to 400 | 1,000 to 2,000 | Above 2,500 | Above 5,000 |
| Final Stage Vehicle Weight (1000 lb) | 4 to 15 | 15 to 35 | 35 to 100 | Above 100 |
| Time Period for Experimental Flights | 1961 to 65 | 1965 to 70 | After 1970 | After 1975 |
| Time Period for Operational Flights | 1964 to 68 | After 1968 | After 1972 | After 1976 |
| Duration of Flight | hours | days | months | years |
| Type Construction | Single finalstage vehicle | Modular, with assembly on earth | Modular type with possible assembly in space | Exchange modules in flight from one vehicle to another |

TABLE 2

CHARACTERISTICS OF FUTURE MANNED SPACE FLIGHT OPERATIONS

| | | | | |
|---|---|---|---|---|
| Mission Type | Low Earth Orbits; Suborbital (MERCURY, DYNASOAR I) | Higher Earth Orbits and exploration (APOLLO) | Near Earth and Lunar Space Stations and Operation | Interplanetary Exploration and Operation (multi-vehicle squadron) |
| Maneuvering Capability | None for MERCURY Some for DYNASOAR | Ability to change orbits slightly | Prolonged maneuvers | Prolonged maneuvers |
| Primary Power Source | Chemical reaction | Chemical reaction | Nuclear reactor | Nuclear reactor |
| Food Regeneration System | None | Limited | Closed Cycle Type | Closed Cycle Type |
| Number of Men | 1 | 2 to 4 | Above 5 | Above 10 |
| Manned Space Function | Scientific specimen Some Observation | Scientific observation; operate measuring instruments | Same plus in orbit maintenance, servicing and limited assembly | Same plus inter-vehicle transfer and adv. system operation |
| Supply | Carry supplies in initial vehicle | Carry supplies in initial vehicle | Ferry vehicle | One vehicle supplies another |
| Cost per Launch (Million dollars) | 8 to 15 | 50 | Above 150 | Above 250 |

# APPENDIX A

## MANNED SERVICE VEHICLE SYSTEM

### NOMENCLATURE

| | | |
|---|---|---|
| $A$ | = | Development cost of unmanned vehicle to be serviced |
| $A'$ | = | Development cost of manned service vehicle |
| $B$ | = | Production and launch cost of unmanned vehicle |
| $B'$ | = | Production and launch cost of manned service vehicle |
| $t_f$ | = | Time to failure or $t_s$ time to service ($t_o = t_f$) |
| $a$ | = | Percent of failures to be fixed by MSV (manned service vehicle) |
| $n$ | = | Total number of unmanned satellites launched |
| $n'$ | = | Number of MSV launched |
| $t_o$ | = | Operating life time of unmanned satellite |
| $m$ | = | Number of satellites in orbit for a given unmanned system |
| $k$ | = | Number of satellites serviced by a single MSV. Assume launch and orbit injection reliability to be very high |

Cost of unmanned vehicle system with replacements for failed vehicles

$$= \frac{t_o m}{t_f}\left(\frac{A}{n} + B\right)$$

Cost of servicing with MSV for the same time period

$$= \frac{t_o}{t_f}\left(\frac{m}{k}\,\frac{A'}{n'} + B'\right)$$

A manned satellite system will pay if the cost of the manned service vehicle flights plus the cost of replacing those that cannot be fixed or repaired in space is less than the cost of the replacement of satellite vehicles that would have failed in orbit without servicing.

$$\frac{t_o m}{t_f}\left(\frac{A}{n} + B\right) \geq 1 - a \quad \frac{t_o m}{t_s}\left(\frac{A}{n} + B\right) + \frac{t_o m}{t_s k}\left(\frac{A'}{n'} + B'\right)$$

Assume:

$A = \$500$ million

$A' = \$1$ billion

$B = \$4\text{-}1/2$ million (Atlas type)

$B' = \$30$ million (Saturn type)

$$n = m\left[1 + \frac{t_o}{t_f}\right]$$

$$n' = \frac{t_o}{t_f}\,\frac{m}{k}$$

These equations then can be solved for different values of n, n', a, $\frac{t_o}{t_f}$, m and plotted in any number of different ways. Figures 4 and 5 show typical results. A, A', B and B' can also be varied.

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LECTURES IN AEROSPACE MEDICINE

LEGAL PROBLEMS OF FUTURE SPACE EXPLORATION AND TRAVEL

Presented By

Colonel Martin Menter, USAF

Chief Attorney, General Law

Office of the General Council

Federal Aviation Agency

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LEGAL PROBLEMS OF FUTURE SPACE EXPLORATION AND TRAVEL

by

Colonel Martin Menter

At the outset, I should like to state that my comments this morning are my own and should not be construed as representing the views of any agency of the United States.

I would like to think that those who planned this program placed this talk last on the agenda because they were aware of the manner of development of law historically. As the Romans used to say, "Ex Facto Oritur Jus" - or "From the Facts, the Law Arises." In other words, we must first ascertain the scientific facts of space before we can develop responsive principles of man-made law to apply to space activities.

You have been exposed this past week to much of the scientific facts concerning space and space activities. It is entirely appropriate that your attention now focus on some of the legal problems incident to space activities.

Man today has written rules or laws affecting him before he arrives in his cradle at birth until long after he withers in his grave. Each new activity of man to assure its proper functioning in the order of things looks to the formation of legal principles for its protection. Without order we would have chaos, lawlessness, and the arresting of

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further progress of man. There is no exception. The rule of law must be applied in future aerospace activities.

The subject on which I have been asked to speak to you today is "Legal Problems of Future Space Exploration and Travel." I was first rather relieved upon learning of the exact title. Note - it does not call upon me to come up with any suggested solutions to the myriad of legal questions concerning space exploration and travel. Perhaps, I therefore should satisfy my responsibilities here if I but pointed out what some of the legal problems are that are involved in space exploration and travel. These problems vary from the mundane to high sophistication involving both civil and criminal law. Suppose a space ship blasts off into space and after a few days is not heard from again. When does an astronaut's wife become a widow? When may the astronaut's estate be settled? If a murder is committed aboard a space ship, has a punishable crime been committed? Let's get real hypothetical - suppose a child is born during an interplanetary trip or after arrival on Mars or Venus, what is his citizenship? In view of the Lorenz contraction of distance theory and Einstein's concept of time scale variations, when would such a child reach his majority with attendant rights of full inheritance and power to personally dispose of his property? Then there are the more nationally significant and thus more important problems that deserve serious consideration by the world family of nations.

Included among these are - The perennial question of "How far up does a nation's sovereignty extend?"

May a nation lawfully claim sovereignty over a celestial body in space?

Who is responsible for damages to life and property sustained on earth as a result of space activities?

May a private company be permitted to orbit commercial satellites? If so, what are its rights to world-wide benefits accruing therefrom - vis-à-vis, subjacent nations over which the satellite orbits? The possible legal questions appear infinite.

Perhaps, however, and more likely, the Commandant and his staff chose the title of my talk very carefully, being aware that there are too many scientific round pegs and square holes that do not yet readily lend themselves to formulation of firm principles of governing law. Rather than attempt to suggest answers to some of these problems, and especially because many of them are not justiciable, it would be far more profitable for you if your speaker were able to give you an insight as to how law in the past has developed, particularly that which appears to be related or analogous - such as the Law of the Sea and Air Law - and then to consider the application of the concepts examined to space exploration and travel.

I believe that through the ages and today the law on any given

subject reflects man's sense of what is just and proper, as conditioned by his needs and environment.

As the past is prologue, let us briefly examine the history of man and society and the basic concepts upon which law is premised. There are various estimates as to how many billion years ago this universe was formed. Through successive billions of years amino acids were produced which made up the protein of the protoplasm of the living cell. The continued evolutionary development of life on earth brought forth Homo Sapiens about a million years ago. The glacial eras forced man to spread about the earth. At the end of the fourth Ice Age - about 8,000 years ago - man began settling down by the shores of lakes and rivers. Tribal villages grew and society which had originally been organized on a familial or tribal basis assumed the character of a territorial and eventually a political organization. As villages grew, agriculture and animal husbandry developed. Property lines assumed significance. Villages began trading with one another and alliances were formed. While most villages remained agricultural, some became centers of trade, commerce, and manufacture, and grew into cities and metropolises.

What rules governed early man's actions? The early hunter respected tribal boundaries on pain of a retalitory arrow for hunting in another's domain. Social control within these early cultures, as they progressed from family to tribe to city-state, was through their evolved folkways

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and mores and mandates of the family and tribal leader or head of state. Unwritten rules evolved that were believed to emanate from concepts of rational behavior prompted by nature. The development of this philosophical conception is attributed to the Stoics in Greece and was adopted by the Romans. It was known as "jus naturale," or "the natural law" and meant in effect "the sum of those principles which ought to govern human conduct because founded in the very nature of man as a rational or social being. This concept of "natural law" is an underlying principle frequently forming the basis for legislative and judicial actions. It probably is the premise for our common law jury measuring stick of "the reasonable man."

The late Judge John J. Parker, in discussing his concept of law in an article entitled "The Role of Law in a Free Society," originally appearing in a 1950 issue of the American Bar Association Journal and republished in the Association's 1956 anthology The Lawyer's Treasury, stated:

> " . . . There is something . . . in the nature of human beings and of society that they compose that determines how society should act and how the members of society should act toward one another. This is law in its true sense. It must be interpreted in terms of rules and these rules must be enforced by the power of the state . . . ."

An earlier jurist, Hugo Grotius, generally accepted as the father of international law, in his Commentary on the Law of Prize and Booty, written in 1604, made reference to the concept of natural law as a basis

for the law of nations, or international law. In this work, Grotius wrote at length on the concept that the sea and air were common to all and could not belong to any one nation. He stated:

> " . . . all those things which have been so constituted by nature that, even when used by a specific individual, they nevertheless suffice for general use by other persons without discrimination, retain today and should retain for all time that status which characterized them when first they sprang from nature . . . . Air falls into this class: first because it is not possible for air to be made subject to occupancy: secondly, because all men have a common right to the use of air. For the same reasons, the sea is an element common to all, since it is so vast that no one could possibly take possession of it, and since it is fitted for use by all . . . ."

While Grotius' expressions on freedom of air were then academic, not so were his expressions on freedom of the seas. In 1580, Spain had complained to England that Sir Francis Drake had violated Spanish sovereignty in sailing in the Pacific without having obtained Spain's permission. The then Queen Elizabeth rejected the protest, stating that vessels of all nations were entitled to use the ocean. This concept of freedom of the high seas is now one of the oldest accepted rules of international law. Grotius in his later work, in 1625, in Of the Law of War and Peace, modified his concept of total freedom of the seas by recognizing that a coastal State had jurisdiction over the waters a short distance from its shoreline as dominion could in fact be obtained over such regions of the sea. This was early referred to as the "cannon-shot rule" which was generally interpreted as three nautical miles or one sea league from the shoreline. This is the forerunner to our accepted rule of a coastal

State's jurisdiction over its "territorial sea," although you may be aware of the fact that the United Nations Conference of the Law of the Sea failed to reach agreement upon the breadth of the international sea.

The characterization by Queen Elizabeth and Grotius of air as free to all users no longer concerned an academic matter after German balloons drifted into French territory in the latter part of the 19th century. Further, in 1900, Von Zeppelin demonstrated controlled balloon flying and in 1903 the Wright brothers introduced piloted aircraft. In 1909, Louis Bleriot lent further import to the problem of sovereignty over airspace when he piloted a plane from France and landed in England. An international convention was called in Paris in 1910 to consider the problem. The conferees were unable to reach agreement between those favoring freedom of flight and those championing full control of the airspace. Many concepts were then presented similar to concepts now presented as to sovereignty in outer space. Concepts of innocent passage were proposed as well as of a division of the atmosphere. As everyone knows, all nations have rejected the concept of the airspace being free and not subject to sovereignty. In fact, the concept too of innocent passage - accepted in the Law of the Sea for travel through the territorial sea - has been rejected in Air Law. Article 1 of the Chicago Convention of 1944 reflects the current internationally accepted concept that " . . . every State has complete and exclusive sovereignty over the airspace above its territory."

Now let us consider, in relation to what has already been said, some of the legal problems incident to space exploration and travel. First, the question that has been most frequently raised concerns whether overflights in outer space violate the sovereignty of the subjacent State? In other words, does a nation's sovereignty extend above the airspace into outer space, and, if so, to what distance? As to this problem, it seems to me we are in space law at about the same place where Air Law was a half century ago. Queen Elizabeth and Grotius, in stating that the air should not belong to any one nation, of course, were speaking philosophically as to what in their views was the natural law. This was based on the times when neither lighter than air nor heavier than air vehicles were known. As Grotius modified his views on sovereignty over that part of the seas as comprises the territorial sea to recognize sovereignty in the coastal State for reason of its protection, so too would he probably modify his views of sovereignty in the airspace above a nation for its protection from airborne vehicles. Perhaps we can say in Air Law that the sovereignty that a State asserts in its airspace is analogous to the sovereignty asserted by a coastal State over its territorial sea. Both are for the protection of the State. While both are firmly entrenched principles of international law, neither has yet had international agreement as to the termination of its outer boundary.

I do not believe that the declarations severally by various States and in the Chicago Convention as to sovereignty in the airspace were intended as a determination of the upward limit of sovereignty. No nation to my knowledge has yet acknowledged any upward limit of its sovereignty. When aerodynamics was the sole media and basis of flight, questions raised of jurisdiction were concerned only with the flights envisioned. The terminology employed was tailored to the question then at hand. It was not necessary then to set an upward limit. Sovereignty in the airspace was then sufficient to the need. Even if we desired to adopt a rule of law that sovereignty should end at the upper limits of airspace, such a demarcation could not be drawn. The atmosphere varies in density about the earth. There is no line where it terminates, but molecules of air are found in outer space. One of the findings of the IGY was that in the high atmosphere there is a variance in density by as much as a factor of ten, depending upon the geographic position, time of day, and season of the year. Perhaps outer space beyond the airspace - whatever its boundary - is analogous to the high sea beyond the territorial sea - whatever its boundary. However, the real question here involved is not where does airspace end and outer space begin, as that cannot be determined, but where sovereignty should be said to end. This determination is not one that may be made by the bench and bar, although most writers are of the view that outer space is free to all. We have

progressed in man's evolution that the rule of law here to be obtained, like the early question in Air Law of sovereignty in airspace, is for political determination by the family of nations. In considering this problem, we should be mindful of the observation of General Thomas D. White, The Chief of Staff of the United States Air Force, that in space travel "for all practical purposes air and space merge, forming a continuous and indivisible field of operations."

There have been many proposals to establish the upward limits of sovereignty at varying distances determined by measurement from the earth or other physical phenomenon. These include:

(a) Height to which airborne vehicles requiring aerodynamic lift can ascend - about 25 miles.

(b) Height at which aerodynamic lift ceases entirely, and Kepler (i.e., centrifugal force) takes over - about 52 miles.

(c) Height arbitrarily determined above point where aerodynamic lift ceases but below that at which an unmanned free falling satellite will orbit - between about 52 and 100 miles - the lowest perigee thus far has been about 100 miles.

(d) Lowest height at which an unmanned free falling satellite will orbit at least once around the earth - between 70 and 100 miles.

(e) Height to which subjacent State may exercise effective control.

(f) Height arbitrarily determined above lower orbital limit.

(g) Height at which the earth loses its gravitational effect.

(h) Height without limit.

It is the scientist as much as the lawyer who will be looked to, to recommend the best rule to be adopted. If it appears that the determination should be below that necessary for successful free falling orbit, a proposal approaching that of Mr. Andrew Haley's Von Karmon line, i.e., height at which aerodynamic lift ceases and centrifugal force takes over, has considerable merit. In October 1960, delegates to the International Aeronautical Federation meeting in Barcelona, including scientists from the US and the USSR, agreed on standards for adjudging world space flight records. It was there determined that manned rocket flights would have to reach an altitude of 62 miles to qualify as space flights. This is our first such accord of significance and a valuable precedent to resolution of the problem of how far up a nation's sovereignty may extend.

Is it really important to immediately determine how far out a nation's sovereignty extends? The arguments for urgency generally contend that such determination would assure greater freedom in space activities in that such flights will not be subject to objection from an overflown subjacent State. However, agreement on the upward limit of sovereignty would not terminate a right of a subjacent sovereign to take action against a hostile satellite above it. For example, the United States and Canada have established zones beyond their territorial sea in which they may lawfully

take defensive action against any hostile act toward them. A hostile act in outer space above any subjacent State could be equally as unpalatable as if committed within its airspace. It is the nature of the activity in space above a subjacent State, rather than the upward extent of its sovereignty, that will determine the tolerance of such State to a satellite orbiting above it. As up to the present, all satellite overflights have been governmental, experimental flights for peaceful purposes, no nation has objected. In fact, it has been generally concluded that a rule of international law was evolving that as long as orbiting space objects or vehicles were not equipped to inflict injury or damage, it did not infringe on the rights of other States overflown. From a security viewpoint, it does not seem to me that an early determination of the upward extent of sovereignty is necessary.

Rather than security providing the impetus for the early resolution of this problem, a new factor has been introduced which suggests for the first time to my mind that early resolution may be desirable. This factor was the recent announcement by Dr. T. Keith Glennan, the Administrator of the National Aeronautics and Space Administration, that NASA, to the extent of its statutory authority, will make vehicles, launching and tracking facilities and technical services available at cost to private companies. As to his reasons therefor, Dr. Glennan stated:

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"Traditionally, communications services in this country have been provided by privately-financed carriers competing with one another to serve the public interest under federal controls and regulations. There seems to be no reason to change that policy with the advent of communications satellites."

In this connection, on December 7, 1960, Mr. Paul Dembling, the Assistant General Counsel of NASA, in an address at the American Rocket Society meeting in Washington, D. C., stated:

"The American Telephone and Telegraph Company announced recently that it is willing to spend millions of its own money on launching, ground transmitters, receivers, and spacecraft for an initial system of 30 communications satellites. These plans contemplate having an experimental satellite in orbit within a year. The band width sought for initial experiments will permit either one-way television or voice . . . communications . . . ."

Resolution of the problem of sovereignty in outer space might well remove the basis for a claim by the subjacent State overflown of a right of taxation of the private company owning the satellite or of the application of its laws, such as regarding slander or censorship, to transmissions of the satellite.

Launching of satellites by private concerns also lends impetus to the need for establishing criteria for launching and use of such satellites, for fixing the "nationality" therof and of future spacecraft, perhaps similar to that provided by registration of aircraft under the Chicago Convention. We should seek a uniform system of markings and recording of space launchings and for the return to the launching nation of the remains of a downed satellite or spacecraft. International agreement

should be sought to establish uniform rules of liability for damages sustained from satellite activities and perhaps establishing a maximum limit of liability. We have examples of similar undertakings in Air Law in the Warsaw Convention, The Hague Protocol, the Rome Convention and others currently under ICAO consideration. I believe the rule of absolute liability should obtain similar to that early provided in domestic legislation in the "Uniform State Law for Aeronautics" which reads:

> ". . . the owner of every aircraft which is operated over the lands or waters of this state is absolutely liable for injuries to persons or property on the land or water beneath caused by the ascent, descent, or flight of the aircraft, or the dropping or falling of any object therefrom, whether such owner was negligent or not, unless the injury is caused by the person injured or the owner or bailee of the property injured."

I should mention that persons suffering damages today as a result of United States space activities are not without some remedy. The United States in a series of statutes has waived its sovereign immunity and has provided claims redress procedures for injuries to persons and property. Most of these statutes were enacted prior to satellite launchings, but, nevertheless are sufficiently broad to encompass space operations. For example, under section 2733 of title 10, United States Code, the Secretary of a military department, or the Judge Advocate General of his department if designated by the Secretary, may settle and pay in an amount not more than $5,000 for damage to real or personal property or personal injury or death caused by a member of the military

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department - including civilian officers or employees - "acting within the scope of his employment, or otherwise incident to non-combat activities of that department." This statute is popularly known as the Military Claims Act. Recovery thereunder need not be based upon negligence. This statute is applicable only to U. S. citizens, except that recovery may be permitted a noncitizen where the incident giving rise to the claim occurred in the United States.

In section 2734 of title 10 of the United States Code, authority is given the Secretary of a military department to provide for settlement and payment of any claim for not more than $15,000 for real or personal property damage or personal injury or death suffered outside the United States, its territories or possessions by an inhabitant of a friendly foreign country. This provision of law is generally referred to as the Foreign Claims Act. Recovery thereunder also need not be based upon negligence but the damage, injury, or death must have been "caused by, or is otherwise incident to noncombat activities of, the armed forces . . . or is caused by a member thereof or a civilian employee of the department concerned." If the amount of the settlement under either section 2733 or 2734 should exceed the statutory authority of the Secretary, he may certify such claim to Congress for payment from appropriations made therefor by the Congress.

Further statutory authority is granted for administrative settlement

and for suit against the United States by the so-called Federal Tort Claims provisions of title 28 of the United States Code. Section 2672 gives the head of each Federal agency authority to settle up to $1,000 for loss of property, injury, or death:

> ". . . caused by the negligent or wrongful act or omission of any employee of the Government while acting within the scope of his office or employment, under circumstances where the United States, if a private person would be liable to the claimant in accordance with the law of the place where the act or omission occurred."

Here, the term "employee" is defined to include military personnel. The act causing the damage, injury, or death must have occurred in the United States and not have arisen "out of combatant activities of the military . . . forces . . . during time of war."

Section 2674 of title 28, United States Code, authorizes Federal liability by court suit "in the same manner and to the same extent as a private individual under like circumstances." Thus no maximum limitation of amount of recovery by judgment is imposed. Note is here made, however, of the recent observation of Mr. Spencer Beresford, Special Counsel to the House Committee on Science and Astronautics, of the possibility that a court may not permit recovery under the Federal Tort Claim Act if it finds the Government's space activity concerned constitutes a "discretionary function" exemption, under section 2680(a) of title 28, United States Code.

Section 203 of the National Aeronautics and Space Act of 1958 grants the National Aeronautics and Space Administration authority to "plan, direct, and conduct aeronautical and space activities" and further "to consider, ascertain, adjust, determine, settle, and pay," in satisfaction of any claim up to $5,000 "for bodily injury, death or damage to or loss of real or personal property resulting from the conduct of the Administration's functions . . . ." A meritorious claim in excess of $5,000 may be reported by the Administration to the Congress for its consideration.

Where the redress sought is against a foreign country, the avenues for recovery would be (1) in accordance with the law of the foreign country by the claimant acting personally or through a local agent, (2) through diplomatic channels, or (3) by a suit filed by claimant's government on his behalf in the International Court of Justice. Jurisdiction of the International Court of Justice, however, would not obtain unless the respondent country has generally accepted the Court's compulsory jurisdiction or submits thereto in the particular case.

Certainly, space exploration and travel will require allocation of frequencies for communication transmission. Fortunately, this is one area where international agreement is already underway via meetings of the International Telecommunications Union in which both the United States and the USSR are active participants. Early agreement is

necessary on allocation of portions of the spectrum for astronautical communication and on termination of radio satellite transmissions when the transmission usefulness has been expended.

I believe that one of our major legal problems in future space travel and exploration concerns the vital question whether the moon and other planets in space are validly subject to claims of sovereignty by individual States. Many persons have stated their belief that such celestial bodies are not subject to claims of sovereignty. To my mind, unless we have an international law governing claims of sovereignty over land areas on earth will apply to celestial areas in outer space. President Eisenhower, in an address on September 22, 1960, before the United Nations advocated early agreement among the family of nations that "celestial bodies are not subject to national appropriation by any claims of sovereignty." Of course, some jurisdiction may be necessary on these celestial bodies. Such could be exercised by the United Nations or by a trusteeship on behalf of and under policies prescribed by the General Assembly. Vesting the rights of sovereignty in the United Nations over celestial bodies should give further assurance to the successful growth of such world organization and should tend to more readily assure the fulfillment of the policy of the United States, as expressed by our Congress in the initial section of the National Aeronautics and Space Act of 1958, "that activities in

space should be devoted to peaceful purposes for the benefit of all mankind."

While the United States earnestly advocates that activities in outer space be devoted to peaceful purposes for the benefit of all mankind, it must at all times guarantee the preservation of our national existence. That our military space activities are lawful and in accord with the concept of peaceful uses of outer space may readily be seen from an examination of the recent American Bar Foundation "Report to the National Aeronautics and Space Administration on the Law of Outer Space." A major portion of this report was released by NASA to the public on December 5, 1960. The report purports to reflect the consensus of existing writing on the Law of Outer Space. Under the heading "The Problem of 'Peaceful Purposes': Military Uses," the release at page 29, in relation to the word "peaceful," states:

> ". . . In the sense of the [U.N.] Charter and in international law generally, it is employed in contradistinction to 'aggressive'. It seems to have been used in this sense — which we believe to be a proper one — in various Congressional resolutions dealing with space activities. Thus any use of space which did not itself constitute an attack upon, or threat against, the territorial integrity and independence of another state would be permissible; the high seas, for example, can be used for the maintenance of a naval force-in-being without any violation of international law, and may be employed 'peacefully' for manoeuvres and testing of weapons . . . ."

Continuing from the NASA release of the report, at p. 30:

> ". . . . For the time being it seems that the only uses of space that are prohibited are those that fall within the prohibition

> of the Charter, and that until a disarmament agreement dealing with space activities can be arrived at, the United States is justified in using space for non-aggressive military uses consistent with the terms of the Charter. Such use is clearly in accordance with existing international law, and the United States would have no embarrassment in asserting that it is 'peaceful' . . . ."

I believe the remarks of Major General Albert M. Kuhfeld, The Judge Advocate General of the United States Air Force, given at the annual dinner of the Association of General Counsel, on November 18, 1960, to be here particularly apropos. He stated:

> "As a nation on the threshold of the space age, we advocate that activities in outer space be devoted to peaceful purposes for the benefit of all mankind. In so doing, however, we do not intend to jeopardize our national security. These are not inconsistent objectives. We have entered into international agreements for civil aviation without limiting our military security. In fact we have developed a Strategic Air Command that has assured the maintenance of peace. We cannot let our guard down and I am confident you agree with me that our nation must maintain in the space age the best military posture that our industrial concerns, in partnership with our military forces, can produce in order to assure peace and deter aggression."

I do not mean to imply from what I have said that we are devoid of law here on earth to govern our activities in space. Man yet remains an earthman as he extends his activities into space. The development of his missiles and satellites, their commercial or military use, and the legal responsibilities of persons connected therewith--whether as employees, contractors, or passengers--are all presently governed by much law. The rules of contracts, agency, torts, conflicts of law, and international law, among others, will play their role. This body

of law was present at the birth of the airplane and applied during the growth of aviation. When new factual situations arose without any precedent in this further evolution of man and society, man's wisdom gained from his past experiences was the "jus naturale" and the base upon which the rule of law was extended to bridge each hiatus. Zeppelin and Bleriot did not defer their flights until the new legal problems were resolved. Their flights presented the ponderous problems of sovereignty within the airspace. These were generally resolved by the makers of policy by statutes and international agreements. Thus far in the space age we have only the same earthman and countries involved as have been involved in the air age with the development and use of the airplane. Problems of security did not stop those nations that were so inclined to enter into conventions and mutually beneficial agreements as to international aerial activities. Resolution of the new legal problems ushered in with the space age similarly rests on the willingness of the nations of the world to resolve them. As the scientist and attorne agree as to factual sufficiency of scientific data acquired, the problem areas may be presented to representatives of national governments for resolution into mutually acceptable rules to govern space activities. Where additional scientific data are not necessary, problem areas may be currently resolved by mutual accord of the family of nations. The United Nations, which has already undertaken to attempt to identify legal

problems incident to the exploration of outer space, is the appropriate agency to seek meaningful international agreements. Such agreements, including, it is hoped, provision for settlement of disputes by recognized international tribunals, will reflect a composite view of man's sense of what is just and proper, as conditioned by his needs and environment and will constitute a major part of Aerospace Law.